GEOTECH : AN EXPERT SYSTEM FOR GEOTECHNICAL ENGINEERING APPLICATIONS

A Thesis Submitted
in Partial Fulfilment of the Requirements
for the Degree of
MASTER OF TECHNOLOGY

by
PARIKH SANJAY A.

to the

DEPARTMENT OF CIVIL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY, KANPUR
MAY, 1989

5/5/89.

CERTIFICATE

This is to certify that the work entitled "GEOTECH· AN EXPERT SYSTEM FOR GEOTECHNICAL ENGINEERING APPLICATIONS " is a work carried out by Mr. Sanjay A. Parikh and that it has not been submitted elsewhere for a degree

3/5/89

(Dr. N.S.V.Kameswara Rao)
Professor of Civil Engg.
& Head, Computer Centre,
INDIAN INSTITUTE OF TECHNOLOGY
KANPUR - 208016.

May 1989

TO

HDH. PRAMUKH SWAMI MAHARAJ

ACKNOWLEDGMENT

I wish to express my sincere gratitude to Dr. N S.V KAMESWARA RAO, my thesis supervisor, for his constant guidance, suggestions and encouragements which made it possible to complete this thesis. The experience I have gained by working under him is an invaluable possession of my life.

Thanks are also due to Dr M.R MADHAV, Dr. P.K. BASUDHAR and Dr PALANISWAMI for their invaluable help.

I am grateful to my friends specially Samir Chauhan, N.C Bohra, Hitesh Dholakia , Nilesh Shah, Prasad Bhatt and Maj V.I Trivedi for their help and encouragements.

-Sanjay Parikh

CONTENT

LIST OF FIGURES

ABSTRACT

Geotechnical engineering is a field where experiential knowledge has no substitute. Making experts' knowledge explicit, and documenting and transferring it can have a grate impact on the state of practice. The knowledge based expert system approach seems particularly suitable for these characteristics and goals.

GEOTECH, an expert system has been developed to assist the user in designing the appropriate type of shallow foundation for given conditions. It is capable of calculating bearing capacity, settlement and ultimately design of foundations It considers various ground conditions like soil type, soil properties, water table etc. and structural details like load, column type, column size etc.

This is a forward chaining system written in COMMON LISP. It handles uncertainty and resolves conflict in working memory, includes back analysis, explanation capabilities and help facilities

The system has been tested for few cases Performance of the system has been found to be entirely satisfactory. Although system is developed for geotechnical engineering applications, several of the ideas and issues discussed also apply to the other areas of engineering

CHAPTER 1. INTRODUCTION

1.1 GENERAL -

Foundation is one of the most important parts of any civil engineering structures Since all structures are supported by foundations and ultimately by soil or rock, the success of project depends on properly designed foundations

Building foundations should be capable of carrying an imposed loading without undergoing movement that causes structural damage or affects the facility's planned usage These considerations require that the soil responsible for supporting a foundation not be stressed beyond its strength limits. Simultaneously, the deformations resulting within this soil because of loading and action of natural forces cannot be excessive The pressure that a foundation unit can impose onto the supporting earth mass without causing overstressing (or shear failure) is the soil's bearing capacity. Deformations occurring because of foundation loading usually cause settlement. The magnitude and type of loading (static, live or repetitive), the foundation performance requirements (how much settlement is permissible) and properties of supporting soil all have influence on the type and size of foundation and its behavior.

Purely empirical to theoretical methods have been developed to arrive at proper design of foundations Methods in widespread use for determining a soil's bearing capacity include the application of bearing capacity equations, the utilization of field test data obtained during soil exploration and the practice of relating the soil type to a presumptive bearing capacity

recommended by building codes Settlement methods include estimating compressibility or volume change characteristics, performing insitu tests and laboratory compression tests The point is made that the various methods give different answers and some methods are only suitable for very narrow ranges, it is necessary to select best method, based on the past experiences of the several experts for the given conditions. The suitability of particular method can only be judged by an experienced expert Hence foundation engineering profession is considered an "art" Scientific method and principles are utilized, but exact answers are not always expected Final decisions concerning best foundation type,design criteria etc are greatly influenced by experience

1 2 IMPORTANCE OF EXPERT SYSTEM APPROACH IN GEOTECHNICAL ENGINEERING -

Expert System is a computer program that uses expert knowledge and rules of thumb (whenever information is inadequate) to give advice and solve problems which usually require the abilities of human expert [see section 1 3] Geotechnical engineering (foundation and earth work engineering) is the area of civil engineering most recognized for the use of expert knowledge. Scientific theories, analytical techniques and experimental methods provide only a fraction of information needed to make the decision, experience does the rest, playing an important and often decisive role This was clearly expressed in the following quote from Terzaghi (father of geotechnical engineering) and Peck (1967)

"In foundation and earthwork engineering more than in any

other field of civil engineering, success depends on practical experience The design of ordinary soil-supported or soil-supporting structures is necessarily based on simple empirical rules can only be used by the engineer who has a background of experience "

The expert system approach, one of the areas of Artificial Intelligence(AI) is particularly suitable to these characteristics and needs of geotechnical engineering. In addition, expert systems can bring other benefits like :

a Systematic consideration of all facts relevant to a task

b The potential use of many field and level of expertise in solving problem

c The formalization of existing knowledge (which can be used in instruction)

d The clarification of phenomenon behind the problem.

1.3 ARTIFICIAL INTELLIGENCE AND EXPERT SYSTEMS :-

Artificial Intelligence (AI) is concerned with designing intelligent computer systems, that is, systems that exhibit the characteristics we associated with intelligence in human behavior-understanding language, learning, reasoning, solving problems and so on (Barr & Feigenbaum 1981)

AI seeks to transform the way we interact with the computers, enlarge the 'cognitive' abilities of the computers, thereby opening up many new application areas like Expert System etc., besides making effort to provide a computational theory of intelligence. AI research may be classified into seven categories as shown in figure 1.1 (Adeli 1988).

An Expert System(ES) is an 'intelligent' program that can play a role of human expert in restricted domain, which uses complex inferential reasoning or logical decisions. Generally ES uses heuristics knowledge or rule of thumb These heuristics are generally accumulated by a human expert over a number of years

An ES must also be able to .

- engage in a dialogue with a user to acquire the relevant detail of the problem.
- explain the problem solving process
- get easily modified as new discoveries are made
- deal with partial information

1.4 ARCHITECTURE OF AN EXPERT SYSTEM :-

In developing an ES, the programmer programs the computer on what to do without telling it how to do it. The present ES is based on the most popular ruled-based system or production system The basic components of the system are [Fig 1.2]·

1.Knowledge Base is the repository of information available in a particular domain. The knowledge base may consist of well-established and documented definitions, facts and rules, as well as judgmental information, rules of thumb etc

2.Inference Mechanism controls the reasoning strategy of the ES In rule-based systems the inference mechanism determines the order in which rules should be invoked and resolve any conflict among the rules when several rules are satisfied simultaneously.

3 Working Memory (or global database) is a temporary storage for the current state of specific problem being solved. Its content changes dynamically and includes information provide by the user about the problem as well as information derived by the system.

1.5 MOTIVATION AND SCOPE :-

Shallow foundations are the commonly occurring type of foundations for the most civil engineering structures. Final decisions concerning best foundation type, its design criteria etc are greatly influenced by experience of designer. In design offices, engineers are using the different methods available for shallow foundation designs based on their past experience and their concept regarding local site conditions. Design of shallow foundation depends upon various factors like soil stratification, properties of soil, ground water table, structural load, natural forces etc. Different methods are available in relevant books, papers and codes Different methods require the different types of data obtained from various laboratory and field tests. These methods are empirical, semi-empirical or theoretical and consider only a few of the relevant factors Hence they are suitable for very narrow ranges. There is no unique solution to design problem and it is very difficult to arrive at logical conclusions without sufficient experience. Lack of experience may lead to unsafe or very conservative designs

This is for such problems requiring the search in solution space that expert system is most suitable.

Thus the important motivations behind the present work are :

a to increase the efficiency of an expert

b to provide aid to insufficient experienced person for making and conforming his decisions.

c to incorporate additional information in the area

d preserving the expert knowledge for the new generation to use

and build upon

e to act as a teaching aid

A forward chaining ES written in COMMON LISP has been developed for the shallow foundation designs keeping in mind practice in our country. This system can be used for the following purposes :

a Finding ultimate bearing capacity of shallow foundation
b Finding ultimate settlement of shallow foundation
c Checking the safety of foundation against shear failure
d Checking the safety of the foundation against the excessive settlement
e Geometric designing (i.e selection of type, shape, size and depth) of shallow foundation for given structure

This is highly interactive type of system through which user can supply the data regarding site conditions, structural loading etc. System provides the required solutions through user friendly interfaces. Such system could be an excellent tool in consulting offices for practice

1.6 ORGANIZATION OF THE THESIS :-

Chapter 2 discusses the basic concepts regarding development of any expert system First part of the chapter 3 gives the general overview of shallow foundation design procedure, remaining part of the chapter deals with the details of an ES developed for shallow foundation design. Conclusions, limitations and scope of future work are outlined in the chapter 4.

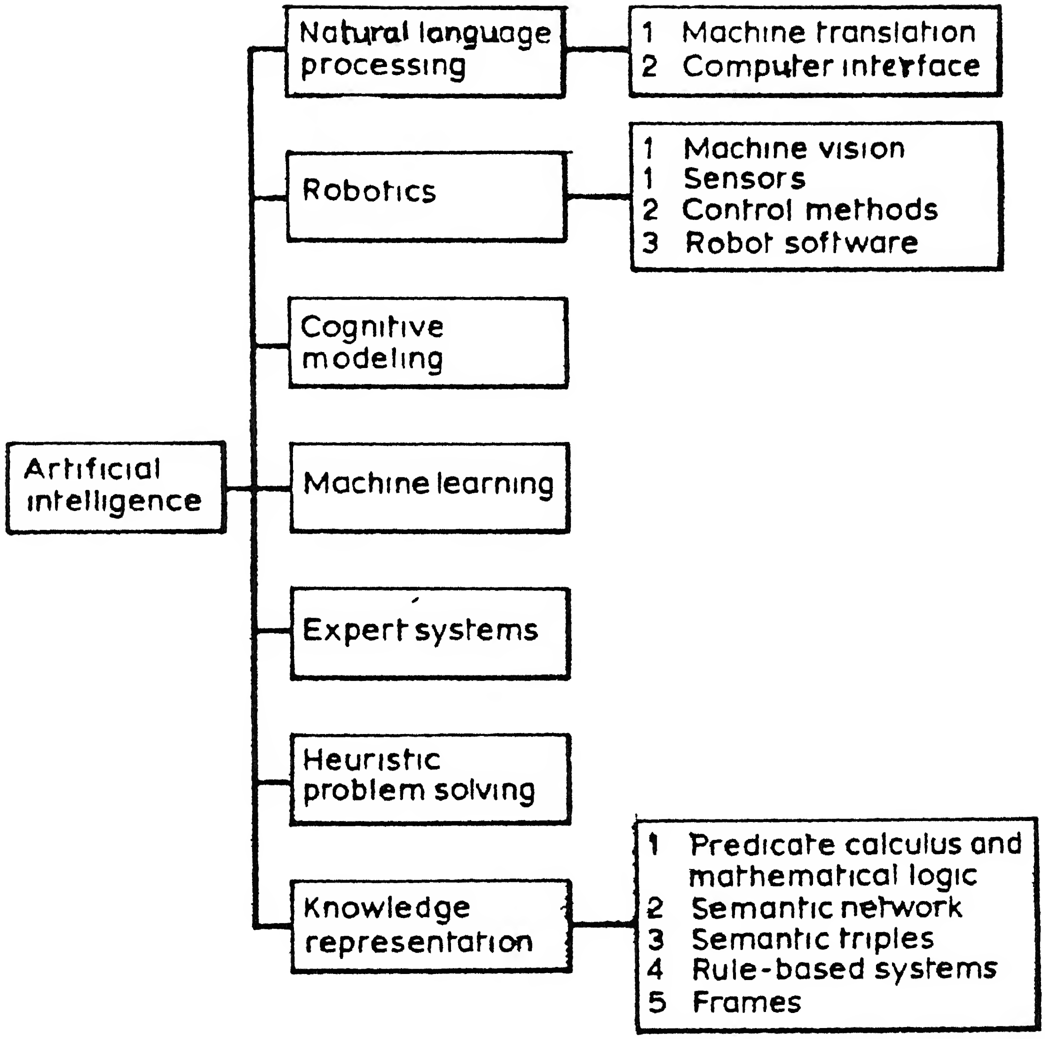


Fig. 1 . 1 Research in artificial intelligence (AI)

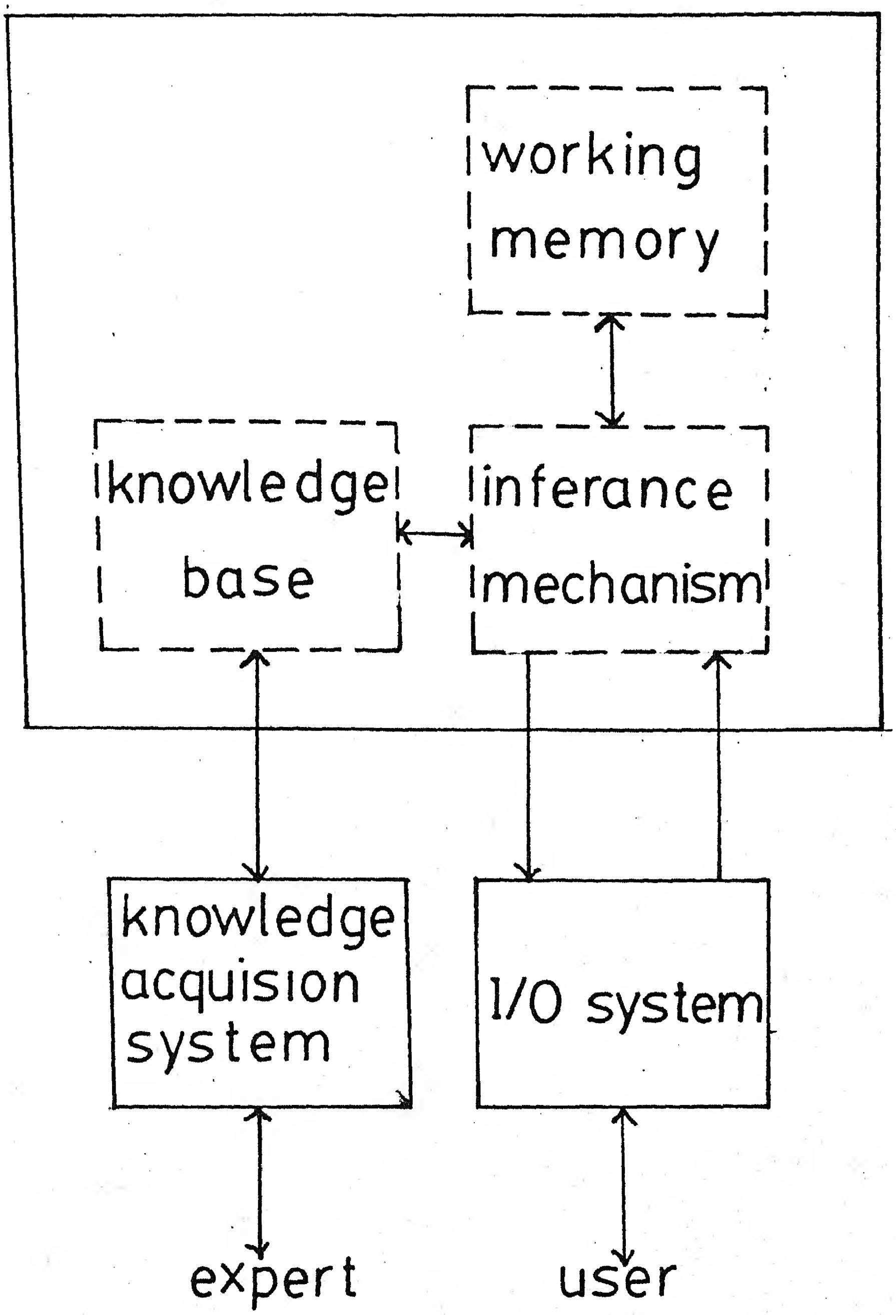


FIG 1.2 ARCHITECTURE OF AN EXPERT SYSTEM

CHAPTER 2. BASIC CONCEPTS FOR BUILDING EXPERT SYSTEMS

2.1 GENERAL :-

Basic steps for the development of an EXPERT SYSTEM (ES) are explained in this chapter Almost all the ES can be developed in the same way irrespective of the domain of the expertise (i e. knowledge base)

The major steps in development of an Expert System are shown in the Fig 2.1.

2.2 AI LANGUAGES AND PROGRAMMING TOOLS :-

Most ES are developed by using either "PROGRAMMING LANGUAGES" such as FORTRAN, PASCAL, LISP or "EXPERT SYSTEM TOOLS" such as EMYCIN, KAS, KEE

Very few ES have been developed in procedural languages like FORTRAN, PASCAL, C etc. Majority of ES have been developed in symbol manipulating languages such as LISP and PROLOG, as they have certain advantages over procedural languages. If considerable numerical algorithmical computation is involved in addition to symbolic manipulation, than by using any of the procedural languages, one can take the advantage of computational power of the language

To facilitate the development of ES, expert system programming environments or tools have recently be developed They contain specific knowledge representation methods and inference mechanisms They are easier to use but less flexible than an AI

language such as LISP ES tools will be particularly useful when ES is to be developed in a relatively shorter time period. [Analysis of some fielded ES shows that 80% of these are developed by using ES tools (Harmon et. al. 1988)]

2.3 KNOWLEDGE REPRESENTATION :-

Knowledge representation is a process of structuring knowledge about a problem domain in a way that makes it easier for computer to solve the problem. The production system (rule-based system) has been the most favorable representation approach for building ES A production system is a collection of rules which consist of an IF part and THEN part or antecedent-consequent or situation-action parts. The general form for the rules is

```
RULE N
 IF  [ (antecedent 1)
       (antecedent 2)
       . .. .....    ]

THEN [ (consequent 1)
       (consequent 2)
       .. .  ....... ]
```

Here each rule represents an independent chunk of knowledge and hence more understandable, easier to modify and context independent Antecedent can be considered as a pattern (see section 3.3 4) and consequent as a conclusion or action to be taken. Production rules facilitate the generation of explanations because of the rules can easily be transformed into questions

2.4 REPRESENTING UNCERTAINTY IN THE KNOWLEDGE BASE :-

Since the knowledge base of an expert system is a repository of human knowledge, and since much of a human knowledge is imprecise in nature, it is usually the case that the knowledge base of an ES is collection of rules and facts which, for the most part, are neither totally certain nor totally consistent. Now, as a general principal, the uncertainty of information in the knowledge base of any question-answering system induces some uncertainty in the validity of conclusions Hence, to serve a useful purpose, the the answer to a question must be associated with an assessment of reliability For this reason, the knowledge base of an ES is equipped with a computational capability to analyze the transmission of uncertainty from the premise to the conclusion and associate the conclusion with what is commonly called a <u>confidence factor</u>

Various methods used in ES to deal with uncertain or incomplete information are

<u>(a). Certainty Factors</u> - Many ES like MYCIN (Buchanan & Shortliffe 1984) are using certainty factors to deal with uncertainty in the knowledge base Each rule is assigned a certainty factor usually in the range -1 to 1 (or Ø to 1 or Ø to 1ØØ) Certainty factors indicate the level of confidence in the piece of information. They are simply informal measures of confidence and not probabilities. Simple rules are used to combine the uncertainties in the various pieces of information In MYCIN, for example, the following formulae are used

$$CF(X,Y) = \begin{cases} CF(X) + CF(Y) - CF(X).CF(Y) & \text{when } CF(X) \ \& \ CF(Y) > \varnothing \\ \dfrac{CF(X) + CF(Y)}{1 - MIN [\, |CF(X)| , |CF(Y)| \,]} & \text{when } CF(X) < \varnothing \text{ or } CF(Y) < \varnothing \\ - CF(-X, -Y) & \text{when } CF(X) \ \& \ CF(Y) < \varnothing \end{cases}$$

Where CF(X) is the certainty factor for evidence or fact X, CF(Y) is the certainty factor for evidence Y, and CF(X,Y) is the combined certainty factor. The range of certainty factors are +1 (for total belief) to -1 (for total disbelief)

(b). Bayes Theorem .- Bayes theorem is well known in statistical and probability literature like Benjamin & Cornell (197Ø) [Adeli 88] One can use this for representing uncertainty in the knowle@ge base It provides a method for calculating the probabilities of an event or fact based on the knowledge of prior probabilities

c). Fuzzy Logic :- Uncertainty can be represented in the nowledge by theory of fuzzy sets originated by Zedeh (1965). In he crisp set theory, an element is either in the set or not in ne set Thus, it may be said that the membership degree of the lement in the set is binary, that is either one or zero The otion is generalized in the theory of fuzzy sets In this theory, element may be in a set with a degree of membership between Ø d 1. Therefore, a fuzzy set consist of a number of elements with signed degree of membership The degrees of membership are llectively called the membership function.

2.5 INFERENCE MECHANISM :-

The control system or inference mechanism manages the firing of rules. It has to decide which of the rules are applicable. The two main inference mechanism are forward-chaining and backward-chaining.

(a). Forward Chaining (or Data-driven Control Strategy) :- In this inference mechanism, rules are scanned until one is found whose antecedents match the information for the problem entered in the working memory. Then, the rule is applied and the working memory is updated. This process is repeated until the goal state is achieved or no usable rule is found. If the goal state is not known or the number of possible outcomes is large then the forward chaining mechanism is often advantageous.

(b). Backward Chaining (or Goal-driven Control Strategy) :- In this inference mechanism, rules are scanned and those whose consequent actions can lead to the goal are found. For each of these rules a check is made whether its antecedents match the information in the working memory. If they all match, the rule is applied and the problem is solved. If there exist an unmatched antecedent a new subgoal is defined as 'arrange conditions to match that antecedent'. This process is applied recursively. If the values of goal state are known and their number is small then backward chaining seems to be quite efficient.

(c). A Combination Of Backward-chaining and Forward-chaining (The Hybrid Approach) :- This approach can be utilized through the use of 'black board' environment. The blackboard model is a structured type of opportunistic reasoning model in which chunk of knowlege

are used backward or forward at the best opportunity.

2.6 KNOWLEDGE ACQUISITION :-

Knowledge acquisition is a process which facilitate the structuring and development of the repository of the information available in a particular domain. The knowledge may be acquired from various means :

1. From literature i.e. books, manuals, journals, articles etc.
2. From domain experts - This can be done by interviews with domain experts or by questionnaires sent to the domain experts.

The knowledge can be well-established equations, graphs, tables of data, algorithmic analysis procedures and experimental knowledge. In developing ES, knowledge acquisition is appearing as the most difficult and time-consuming part.

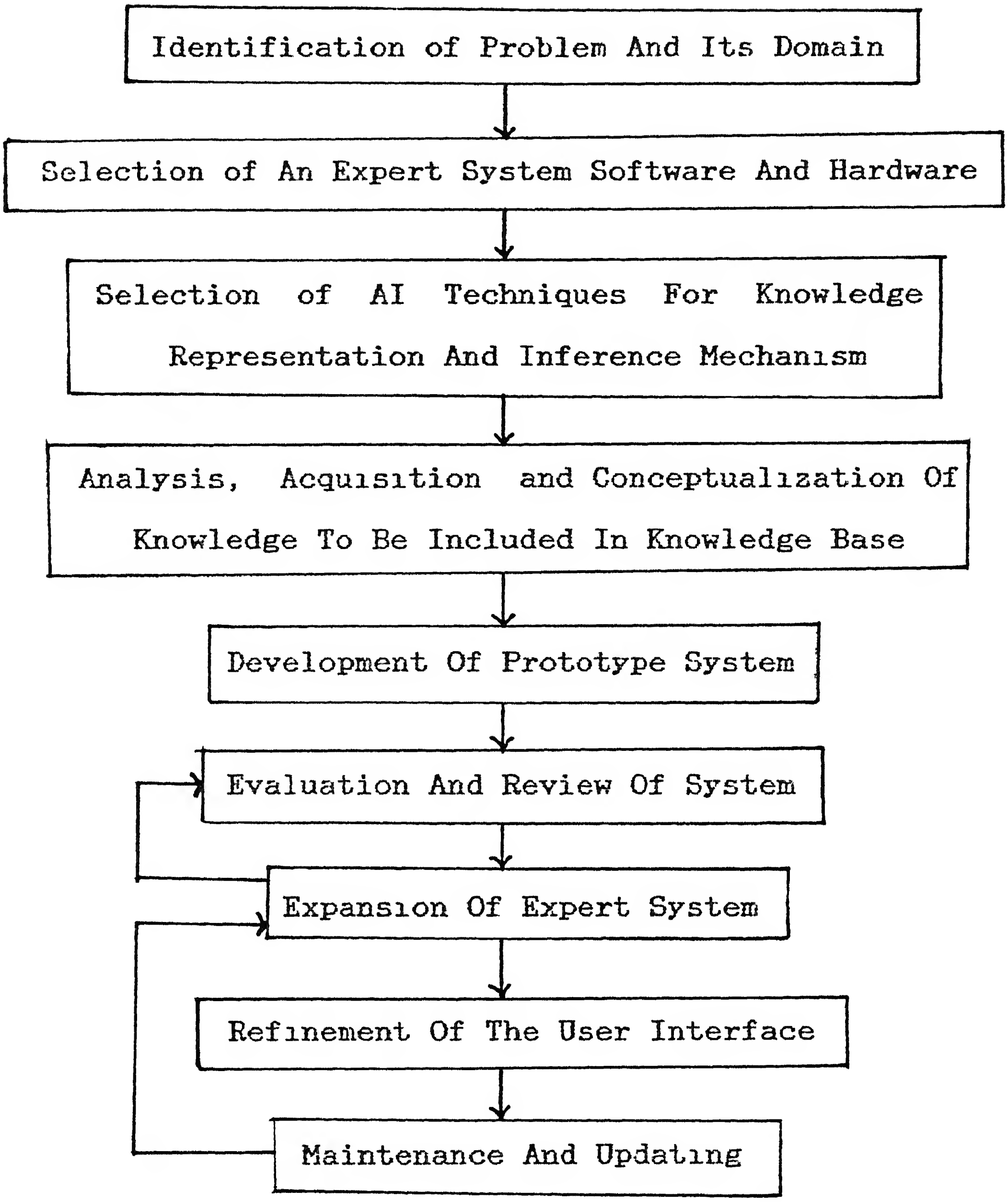

Identification of Problem And Its Domain
Selection of An Expert System Software And Hardware
Selection of AI Techniques For Knowledge Representation And Inference Mechanism
Analysis, Acquisition and Conceptualization Of Knowledge To Be Included In Knowledge Base
Development Of Prototype System
Evaluation And Review Of System
Expansion Of Expert System
Refinement Of The User Interface
Maintenance And Updating

FIGURE 2.1

CHAPTER 3. GEOTECH-AN EXPERT SYSTEM FOR SHALLOW FOUNDATION DESIGNS

3.1 GENERAL:-

In a broad sense, foundation engineering is the art of selecting, designing and constructing the elements (foundation) that transfer the weight of structure to the underlying soil or rock The general overview of shallow foundation design procedure is described in the first section of this chapter

Design of foundation is such a process where experimental knowledge has no substitute. No unique solution can be obtained for given requirements. An ES developed for this problem is discussed in the second section. Basic components of ES developed in the present work, such as knowledge representation, uncertainty in knowledge base, inference mechanism, knowledge acquisition etc. are explained in detail as well as some special features of the system like back analysis, help facility etc are described in this section.

3.2 OVERVIEW OF SHALLOW FOUNDATION DESIGN PROCEDURE :-

3.2.1 INTRODUCTION:-

All structures designed to be supported by earth including buildings, bridges, dams, etc. consist of two parts. These are the super structure, or upper part and the sub structural element which interfaces the super structure and supporting ground. The foundation can be defined as the substructure which is in direct contact with and transferring loads to the ground. Foundation may be broadly classified into two categories·

1. shallow foundations   2. deep foundations

As a rough measure if the ratio of the depth of embedment to width of foundation does not exceed one than it is known as shallow foundation.

3.2.2 GENERAL REQUIREMENTS OF FOUNDATIONS:-

A foundation must be capable of satisfying several stability and deformation requirements such as

1 depth must be adequate to avoid lateral expulsion of material from beneath the foundation

2. depth must be below the zone of seasonal volume changes

3 system must be safe against overturning,rotating,sliding or soil rupture(shear strength failure).

4 total earth movements (generally settlements) and differential movements should be tolerable for both the foundation and super structure elements

5. The foundation should be economical in terms of the method of installation.

3.2.3 DESIGN PROCEDURE:-

Detail description for design procedure and various tests and methods described in the following sections can be found in Kaniraj (1988), Bowles (1982) and McCarthy (1988) The basic block diagram of shallow foundation design procedure is shown in Figure 3 1. The main job of foundation designer is to determine .

a. type of foundation

b shape of foundation

c. size of foundation

d. depth of foundation

It is essential that foundation design must satisfy the general engineering requirements Hence general site condition and various engineering properties of soil are required

3.2.4 SITE INVESTIGATION AND FINDING ENGINEERING PROPERTIES OF SOIL:-

Investigation of the underground conditions at a site is a prerequisite to design of foundations For normal structures, most widely used method of substructure investigation is boring holes into the ground from which samples are collected for either visual inspection or for laboratory testing Fundamental properties of soil like water content, bulk density etc. are also be found by using this samples

The behavior and hence design of every foundation depends primarily on the engineering characteristics of the underlying deposits of soil or rock The most important engineering properties required for foundation design are strength and compressibility Various types of in-situ and laboratory tests like direct shear test, triaxial test, standard penetration test (SPT), cone penetration test (CPT), plate load test, pressure meter test, vane shear test, consolidation test etc. are used to determine these properties.

The data obtained by these tests are used to determine allowable bearing pressure. Allowable bearing pressure is a pressure that can be imposed by the foundation on the soil without causing shear failure (bearing capacity criterion) or excessive deformation (settlement criterion) of soil.

3.2.5 BEARING CAPACITY ANALYSIS :-

Various methods are available for finding bearing capacity of

homogeneous soil from shear strength parameters are due to Terzaghi, Mayerhof, Brinch Hansen, Vesic, Balla, Skempton. The codes such as IS:6403-1981 also enumerate the procedure. Each method gives simple equations more or less of same pattern. For example Terzaghi's equation for continuous footing is .

$$q_{alt} = cN_c + qN_q + 0.5\gamma BN_\gamma$$

where

q_{alt} = ultimate bearing capacity

N_c, N_q, N_γ = bearing capacity factors and depend on angle of internal friction of soil (ϕ)

c = cohesion of soil

q = effective over burden pressure

γ = bulk density of soil

For nonhomogeneous soil mass methods are given by Button, Vesic, Bowles etc. Empirical equations are given by Bowles, Teng, IS 6403-1981 etc. for finding bearing capacity from SPT Correlations for cone resistance of CPT and bearing capacity are given by Bowles, IS:6403-1981, Schemertmann etc. Methods are available for finding bearing capacity using pressure meter test, vane shear test and plate load test etc

3.2.6 SETTLEMENT ANALYSIS :

From compressibility characteristics of soil total settlement can be obtained by using various methods The settlement increases with time and total settlement is given as

$$S_t = S_i + S_c + S_s$$

where

S_i = the immediate or elastic settlement

S_c = settlement due to primary consolidation

S_s = settlement due to secondary consolidation

Different settlement computation procedures can be adopted as follows

1. Elastic displacement method In this case the solutions are derived by the integration of displacement due to elementary force

2 Elastic strain simulation method This method is based on the theoretical relationship between stresses and vertical strain

$$\epsilon_z = \frac{1}{E}\left[\sigma_z \quad \mu\,(\sigma_x + \sigma_y)\right]$$

and thus $$\delta_z = \Sigma \epsilon_z \,\Delta h$$

3 Based on laboratory or field test results Various laboratory tests like consolidation test etc. are used with theoretical expressions. Correlations are given to find settlement using various field tests like SPT, CPT, plate load test etc.

4. Simplified procedures These are not based on rigorous theories. Based on empirical observation they are found to give adequate results.

5. Finite element method: Finite element method can be used to find stresses and displacements in the soil mass

3.2.7 TYPE, SHAPE, and SIZE of FOUNDATION·-

The type and the shape of foundation most appropriate for a given structure depends on several factors The function of structure and load it must carry,the sub structure conditions, the cost of structure etc. Because of interplay of these several factors, there are usually several acceptable solutions. Faced with a given situation, different engineers of long experience may

arrive at somewhat different conclusions Thus judgment plays a primary part One can only use past experience in deciding type and shape of foundation

As for example , one may use

"if area covered by the spread footing is more than fifty percent of total area then mat foundation is more economical"

Geometric dimensions of foundation primarily depend on allowable bearing pressure. Embedded depth of the foundation must be more than minimum required depth. Actual depth at which solution will be optimum, can only be obtained by experienced engineer

For a given load, length and width of the foundation are designed in such a way that imposed pressure will be less than the allowable bearing pressure.

The entire design is iterative and trial and error procedure Allowable bearing pressure depends on dimensions of the foundation and on the other hand dimensions depends on allowable bearing pressure. Dimensions required for different types of foundations are also not known before actual calculations. Designs are for most promising alternatives based on experience Type, shape, depth, width and length of foundation are generally guided by judgment only.

3.3 GEOTECH

3.3.1 GENERAL:-

An Expert System(ES), "GEOTECH" has been developed for the design of shallow foundations. Basic components of GEOTECH are

shown in figure 3 2 . As discussed in previous section design of any shallow foundation is done in three basic steps.

These are

1 The appreciation of general site conditions and determination of soil properties by various field and laboratory methods

2 Calculation of allowable bearing pressure

3 Selection of type, shape and dimensions of foundation element

As an ES for engineering application, GEOTECH differs from the successfully implemented expert system like MYCIN, PROSPECTOR etc , in one respect It not only gathers the necessary data and selects the best methods, but also does the necessary numerical calculations.

3.3.2 HARDWARE AND SOFTWARE:-

A microcomputer has been selected to implement GEOTECH, because of remarkable increase in the power of microcomputers and its software, in recent years. The transportability of GEOTECH is very high as it can be run on IBM PC - XT/AT compatible hardware

Higher level language, COMMON LISP has been used rather than a expert system shell or tool. ES tools are easier to use and by using it ES can be developed within a relatively shorter time period. However, when compared to higher level language like LISP, ES tolls have several limitations as extensively reported by Jackson (1986) It is very difficult to find a ES shell, which satisfies all the requirements of ES under consideration. Even if one such ES shell is available in the beginning of ES development, it is very difficult, if not impossible, to incorporate new features in the system at a later stage. This

consideration is extremely important for a project undertaken in an academic environment where research is of prime importance rather than merely development. Hence a higher level language, <u>GOLDEN COMMON LISP(GCLISP),</u> a version of COMMON LISP on IBM personal computer has been used. Selection of LISP offers the following advantages over the use of conventional languages such as PASCAL, FORTRAN etc.

1. LISP is very powerful in manipulating symbolic expressions.

2. Data and program in LISP have the same form and are treated in the same way. Both data and program are represented as lists. LISP treats other LISP programs as data. A program written in LISP can modify its code as easily as it can change its data.

3. Unlike FORTRAN , due to dynamic creation of variables, LISP functions can recursively call themselves.

4. Memory management in LISP is performed automatically. Lists not in use are erased by the system.

5. LISP programs are easy to debug. LISP functions can be tested independently even though they may call other functions yet to be defined.

6. LISP program has simple and flexible syntax and is rather easy to read. Both lower and upper case letters can be used in defining variables.

7. LISP is a flexible and dynamic language. It can be extended by the programmer by creating new high level functions.

8. In contrast to most other programming languages,variables in LISP are not restricted by type and may have any complicated data structure.

3.3.3 KNOWLEDGE BASE:-

Like most of the existing expert system, GEOTECH utilizes a knowledge representation method that is based on production rules. The advantages of this representation are

- individual rules represents naturally occurring 'chunks' of knowledge
- independence among rules keeps the rule base semantically as well as syntactically modular
- modularity allows for incremental development of the knowledge base Although some people have raised some doubts about these benefits [Jackson P 1986], at present this representation can be the most successful method of representing the knowledge.

A production system (rule base system) is a collection of an IF part and a THEN part or antecedent and consequent or situation and action parts The general form for the rule is

```
Rule S
        IF   [antecedent 1 (condition 1)]
             [antecedent 2 (condition  2)]
             .   .
        THEN [consequent 1 (action 1)]
             [consequent 2 (action 2)]
                     . .
```

The "if" part is usually a boolean combination of clauses and the "then" part specifies a set of actions modifications the working memory As an example, one production rule to determine bearing capacity can be stated as

Rule 107

IF soil system is homogeneous

and soil is cohesion less

and shear strength parameters are known

and mode of failure is general shear failure

and foundation is shallow strip footing

THEN use method of Balla for calculating bearing capacity

Thus the knowledge is stored in the system in a form of production rules

3 3.4 WORKING MEMORY:-

The most basic function of the working memory (WM) is to hold data, often in the form of object - attribute - value triples These data are used by inference mechanism to drive the rules, in the sense that the presence or absence of data elements in the working memory will 'trigger' some rules, by satisfying the activation pattern. If a condition contains no variables, then it is satisfied only if an identical expression is present in the working memory If a condition contains one or more variables, i e if it is a pattern, then it is satisfied only if there exists an expression in WM which matches it in a way that is consistent with the way in which other conditions in the same rule have already been matched

In this context, a simple match is just an assignment of constants to variables which, if applied as situation, would make the patent identical to the expression it match against

Suppose , rule is given [variables are prefixed by *]

If (* foundation depth *number)

(*number is less than *foundation- width)

then (*foundation is shallow foundation)

Here (spread foundation [2x2 5 sq m] depth 1.5 m) satisfies the first condition (*foundation depth *number) with substitution 'spread foundation [2x2.5 sq] ' for *foundation and 1 5 for *number

Subsequent attempt to match conditions in the rule will now be constraint by the substitution derived above . Thus *number must be substituted by 1 5 in (*number is less than *foundation width). If they have a match then rule will be triggered Subsequently variables are assigned other values from WM and matching is checked

3.3.5. UNCERTAINTY :-

Most geotechnical engineering decisions are made on the basis of uncertain and insufficient informations For example, in the case of GEOTECH, the user may not know exactly whether the soil is normally consolidated or over consolidated Modeling uncertainty adds a new dimension to ES, modifying the way inference takes place.

Fuzzy logic, a type of logic using graded or qualified statements rather than statements that are strictly true or false, is employed here for the following reasons

a Much of the uncertainty in empirically-based decisions using natural language words or phrases involves vagueness rather than randomness (Zedah 1984) Vagueness is a type of imprecision

associated with classes in which there is no sharp transition from membership to non-membership. This distinction between Vagueness (or fuzziness) and statistical randomness is important Probability-based methods are adept at qualifying uncertainty based on randomness alone Fuzzy logic provides a systematic basis for qualifying uncertainty due to vagueness and incompleteness of the information in the knowledge base (Zedah 1984)

b In practical engineering applications, the basis for judgment is often an incomplete data set interpreted using empirical methods In such situations, it is misleading to imply a level of precision that is inconsistent with with the methods and data Given these considerations, linguistic quantification of uncertainty seems appropriate

c There is no broad assumption of complete [illegible] of the evidence [illegible] combined using fuzzy logic as [illegible] [illegible] (Zedah [illegible])

3 3 5 1 FUZZY LOGIC BACKGROUND -

[illegible] classical set theory (crisp set), an element is either in the set or not in the set In other words, the degree of membership of an element is binary, either 1 Ø or Ø Ø In fuzzy set theory this concept of membership is generalized An element in a fuzzy set can be partially in the set, say with a degree (or grade) of membership of Ø 7; thus the term fuzzy set This generalization of degree of membership allows a more realistic modeling of many real-word situations, since few complex situations are binary Thus a fuzzy set is composed of several elements along with their associated degree of membership This function is usually called a **membership (or characteristic)**

function.

The basic unit in fuzzy logic is linguistic variable This linguistic variable is used to represent a piece of information in a full way, by using characteristic function Then any natural language qualifier appropriate as a value of this linguistic variable can be represented using appropriate degree of membership For example, a linguistic variable SOIL-TYPE could be represented as a three element fuzzy set with a membership function, as follows

SOIL-TYPE={ μcohesionless/cohesionless, μcohesive/cohesive, μpurely-cohesive/purely-cohesive}

values of this linguistic variable would be in this form

SILTY-SAND = {Ø.8/cohesionless,Ø.4/cohesive, Ø/purely-cohesive}.

3.3.5.2 THE USE OF FUZZY LOGIC IN GEOTECH :-

Two types of uncertainty have been used in GEOTECH

a Uncertainty associated with factual knowledge

b Uncertainty associated with rules.

The uncertainty associated with factual knowledge is included by **"CERTAINTY FACTORS (CFu)"** for the user's response The user's response consist of either a choice among alternatives or numerical data followed by a numerical or linguistic measure of the certainty in the answer, for instance

"Soil is normally consolidated with certainty factor CFu = Ø 9"

or "soil is normally consolidated with high certainty ".

Here certainty factors range from Ø to 1 for no support and the total support in the answer, respectively

Uncertainty associated with the rules are included by

"IMPORTANCE FACTORS (IMF)" in the rules. Importance factors are the measure of relevance of a rule in a decision, ranges from Ø to 1 for no importance to total importance.

Rule 1Ø7, described in section 3.3.3, can be written as

IF soil system is homogeneous (CFu1)
and soil is cohesionless (CFu2)
and shear strength parameters are given (CFu3)
and mode of failure is general failure (CFu4)
and foundation is shallow strip footing (CFu5)
THEN Use method of Balla for calculating bearing capacity with certainty (IMF)

Here CFu1,CFu2 etc. are the uncertainty associated with factual knowledge, either supplied by the user directly (e.g. CFu3) or inferred by the system based on other user supplied data (e.g. CFu2). IMF is the uncertainty associated with the rule.

In general, a rule has several antecedents that represent requirements for the rule to apply. Since each of the matching facts in the working memory may have different certainty factors and each of the antecedents may have different relative importance, a technique is needed to evaluate the combined support of antecedents. For this, different types of mapping functions can be used (Dong et. al. 1988). Currently system is using the mapping function

$$y = f(x) = \frac{\sum_{j=1}^{m} w_j . x_j}{\sum_{j=1}^{m} w_j} \qquad w_j \geq 0$$

where x_j = certainty associated with the factual knowledge

w_j = relative importance of the factual knowledge in

the rule

When a rule is triggered (executed), a combined support of antecedents has been calculated using above described mapping function, this value is called as <u>CFa</u> If antecedents are in disjunctive mode then maximum of w_j x_j is taken in finding CFa Finally, the certainty of the consequent <u>(CFc)</u> is obtained by multiplying CFa with IMF and consequents are stored in to **conflict resolution list (CLIST)** with this obtained CFc

For instance, consider the above described rule 107.

All the antecedents are in conjunctive mode and

IF soil-system is homogeneous with CFu=1 0

having relative weight w =1

soil type is cohesionless with CFu = 0 8

having relative weight w = 0 9

shear strength parameters are given with CFu = 0 75

having relative weight w = 1 0

mode of failure is general with CFu = 0 8

having relative weight w = 0.85

foundation is shallow strip footing with CFu = 0 95

having relative weight w = 0 8

THEN

$$CFa = \frac{1*1 + 0\ 8*0.9 + 0\ 75*1 + 0\ 8*0\ 85 + 0\ 95*0\ 8}{1\ 0 + 0\ 9 + 1.0 + 0.85 + 0\ 8}$$

= 0 859

Balla's method is particularly suitable for shallow strip foundation on cohesionless soils and hence having IMF = 0.95

then

CFc = CFa * IMF

= Ø 859 * Ø 95

= Ø.816

This is the final certainty on "use the Balla's method for calculating bearing capacity" Now, **use Balla's method with CFc = Ø.818 is stored into CLIST.**

3.3 6 CONFLICT RESOLUTION :

After executing rules, consequents are stored into CLIST with appropriate certainties. Conflict resolution refers to the process of selecting the rules to be fired from a set of "executable(triggered)" rules Generally rule having more certainty is fired first and so on But if two executed rules have same consequent with deferent certainties, the rule with more certainty(CFc) will only be fired

As for example two rules concluded

Use Terzaghi method with CFc = Ø.725 (Rule 11Ø)

Use Terzaghi method with CFc = Ø 638 (Rule 122)

Then rule 11Ø will only be fired

This process will continue till the sufficient number of solutions are obtained or no more rule can be fired due to certainty factor(CFc) lower than threshold value and back-analysis will be performed by the system (see section 3 4 3)

3.3.7. INFERENCE MECHANISM :-

The design problems are usually open ended i.e several solution can be obtained for given conditions Forward chaining mechanism will be more efficient for open ended problems and hence

GEOTECH uses forward chaining mechanism It uses the acquired information to evaluate the tree of possibilities, as it progresses through the solution procedure System starts form the given data and tries to satisfy the antecedents of rules. If the antecedents are satisfied than consequents become part of the working memory Now system will try to satisfy antecedents of other rules by using supplied as well as inferred data. This process will continue till the desired goal is achieved or no rule can be satisfied.

As for example

User supplied data Soil is silty-sand

By applying

Rule 7A

IF soil is silty-sand

THEN soil type is cohesionless with CF = Ø 9

the working memory is updated with

[SOIL COHESIONLESS WITH CF = Ø.9]

Now mechanism will try to satisfy the rules whose antecedents contain

'SOIL TYPE IS COHESIONLESS SOIL'

3.3.8 KNOWLEDGE AND KNOWLEDGE ACQUISITION :

It is well recognized that the knowledge incorporated in the system is the most important part of an expert system, however, it is also clear that obtaining that knowledge is the most difficult task in the development. The knowledge for the GEOTECH is based on in-house expertise and relevant literature Majority of the knowledge has been derived by several discussions with expert

faculty members and postgraduate students in geotechnical engineering at IIT Kanpur

At present system consists of 150 rules, many of which are minor goals in themselves. For example, determination of bearing capacity depends on whether the mode of failure is general or local shear failure Making such decision involves the understanding of the soil characteristics. The burden of this decision has been removed from the user by codifying the relevant rules and adding them to the system. This is an important advantage of this approach in that it allows the incremental development of the tool without altering previous works in the most cases

GEOTECH runs in a "rich environment" called "SOILTECH" a geotechnical information facility that can be accessed at any time during execution or independently. These are electronic pages of geotechnical information The information included in SOILTECH relates to various aspects of geotechnical engineering such as soil classification, soil parameters etc.

3.4.SOME SPECIAL FEATURES OF GEOTECH :-

In GEOTECH various special features are incorporated besides basic expert system, to make it more 'intelligent' and 'user friendly'. These features are described in brief in the following sections.

3 4.1 POSING QUESTIONS :

Informations regarding particular problem have to be elicited from the user in a form of question-answer conversation. In the

naive approach, before inference begins all the questions can be asked of the user and the answer stored as facts This, however, does not work satisfactorily Firstly, not all the questions need to be asked. Based on the goal and the user's responses only some of the questions need to be posed to the user. Secondly, questions are asked in the some order keeping focus and user's response in the mind

In GEOTECH, what questions to ask the user and in what order to ask them has been tied to the inference This is accomplished by ASK-QUESTION rules that causes questions to be issued The rules are not treated in any special manner, but name is given to emphasize that they are used for asking questions. For example a typical rule reads as follows .

Rule

If soil is purely cohesive

Then ask

"Give the unconfined compressive strength of the soil".

3.4.2 EXPLANATION :-

Explanation capabilities in ES are generally limited. The system exposed it's line of reasoning by offering explanation of various kinds "WHY" and "HOW" questions can be asked by the user during interaction. "WHY" is user's way of inquiring "Why do you want to know that ? " System will try to justify the question by giving technical informations "HOW" is the way of asking "How did you conclude that ? System will explain the reasons behind the given conclusion

3.4.3 DEALING WITH MISSING DATA :-

Under actual working condition, it is not possible in all the cases to obtain each and every piece of information required under ideal conditions During such circumstances field experts also try to arrive at missing informations by either using indirect methods or judgments based on previous experience To impart the facility to deal with missing information, a special knowledge base has been created in GEOTECH

User can reply as NK(Not Known) to any question However the questions asked by the system are of two types.

a Mandatory questions b Optional questions

Mandatory questions collect that vital information from the user without which nobody can even think of designing a foundation. If the user is not able to provide it, the system can't proceed to design the foundation.

Optional questions are not so critical and user can respond to these questions as "Not Known" The system can infer its value from the special knowledge base when ever possible, only at the expense of confidence in the outcome of the system

Example of mandatory question

* Give the following data for the column 1

Total Load (In KN) = **NK****

* It is impossible to proceed for the actual design without knowing this data Please obtain this data and give it to me

Are you able to give this data now (Y/N) ? **Y**

**THE RESPONSE OF THE USER IS SHOWN IN THE BOLD UNDERLINED WHILE RESPONSE OF THE SYSTEM IS SHOWN IN THE NORMAL WRITE-UP.

Total Load (In KN) = 1800

. . . .

Example of option question :

* Give the following data for soil layer 2

Compression index (Cc) = NK

Void ratio (e_0) = 0.7

[System will infer the value of compression index(Cc) from void ratio.]

3.4.3 BACK ANALYSIS :-

The system response is a list of the most promising alternatives with corresponding confidence factors. Under certain circumstances it is possible that reliability of the achieved goal by selected path is very less or goal can not be achieved by any path for the given conditions. During such circumstances, system should be in a position to recognize and reject such results.

If confidence factor corresponding to derived goal falls bellow a predetermined threshold value(Thv), the result is rejected. If all the possible outcomes are to be rejected because of low confidence factor value then system will try to pinpoint the exact causes of failure by firing CHECK-RULES. CHECK-RULES are the special rules developed for performing back analysis and thus for finding failure.

This type of condition can arise because of three reasons:

1. Poor quality of user supplied data - certainty factor corResponding to supplied data are very low.

2. Insufficient data - data supplied by the user is too less to

arrive at a goal with a reasonable confidence factor

3 Irrelevant data - contradictory data is supplied by the user System will identify the causes and instruct the user to take remedial measures

As for example

+ Soil is classified as a highly cohesive soil and only Standard Penetration Test (SPT) is performed

SPT is not reliable for such type of soil and hence I am not able to find any solution.

I suggest that you should perform either Triaxial Test or Vane Shear Test

3.4 4 HELP SERVICE :-

Help service, particularly on-line help service is an essential characteristic of any good software to make it more efficient and user friendly GEOTECH is equipped with various types of on-line and off-line help services The on-line help services are.

a Unit Conversion and Numeric Key Pad

SI unit system is followed in developing GEOTECH If data is not available in the SI units then by invoking these helps, data can be converted into SI units at any time during conversation

b Dynamic change in data [change data at ANY TIME !] .

During the interaction with the system user has to give several data required by the system If data can not be changed once it has given to the system, a small mistake in giving data will lead the user to start the system again from the beginning This is very time consuming and boring process.

In GEOTECH user can observe any data and correct the mistake, if any, at any time. If data is changed, the system not only changes this particular data but also changes other data inferred from this data This dynamic change in data is essential because system simultaneously infers the necessary data as conversation goes on

As for example

*Give the following details for

Liquid limit = <u>47</u>

Plastic limit = <u>15</u>

System inferred that soil type is CI i.e inorganic clay or sandy clays or silty clays of medium plasticity and stored in working memory and conversation goes on.

Now if user changes data at later stage as

*current value of plastic limit = 15

Enter the new value = <u>35</u>

System will infer the soil type as MI i.e. inorganic silts or silty or clayey fine sand or clayey silt of medium plasticity and working memory is updated with this.

<u>c. Current Help Facility .</u>

When user has some confusion about the question posed or user wants to know about the probable values of the required answer, this help can be used. This help facility tries to make current question more explicit by giving elaborate explanations and approximate range of value, if possible For example,

*HAVE YOU CALCULATED E [Elastic Modules] and [poisson's ratio] values (Y/N) ? <u><F1></u>

ON LINE HELP SERVICE

E = MODULES OF ELASTICITY

IT IS DEFINED AS SLOPE OF THE LINEAR PORTION OF STRESS-STRAIN CURVE

μ = POISSON'S RATIO

IT IS DEFINED AS THE RATIO OF LATERAL STRAIN TO LONGITUDINAL STRAIN WHEN THE APPLIED STRESS IS UNIAXIAL

[PRESS M FOR MORE HELP, ANY OTHER KEY TO RETURN BACK]

M

TYPICAL RANGE OF VALUES OF THE STATIC STRESS-STRAIN MODULES FOR SELECTED SOILS [FIELD VALUES DEPEND ON STRESS HISTORY, WATER CONTENT, DENSITY etc]

[Ref Bowles (1982) pp 67]

SOIL	E KSF	E MPA
CLAY		
VERY SOFT	5Ø-25Ø	2-15
SOFT	1ØØ-5ØØ	5-25
MEDIUM	3ØØ-1ØØØ	15-5Ø
HARD	1ØØØ-2ØØØ	5Ø-1ØØ
SANDY	5ØØ-5ØØØ	25-25Ø

d. System As A Number Cruncher :

User can ask the system to perform particular task by using specified method(s) Thus system can be used just as a

traditional software developed for only numerical calculations

Besides these, various other off-line helps have been provided.

User can know about the different methods accommodated in the system The system also provides IS code and other references, whenever possible After little modifications this can be used as a educational aid

For the beginners system provides help like 'How to use this Expert System ?' 'What is Expert System' 'What is GEOTECH' etc

3.4.3 GRAPHIC INTERFACE :

GCLISP has very limited graphics facility Only two functions a Draw line b Fill area are available Due to this limitation, GEOTECH has very limited graphics facilities. It displays the certain inputs and outputs of the system graphically[fig 3 3] Thus it facilitate the user in checking the given data and better understanding of the output

3.4 PERFORMANCE OF THE SYSTEM :-

Performance of the system has been evaluated by running few cases on the system The performance of the system is found to be entirely satisfactory Two sample sessions are presented in the Appendix-D to illustrate the behaviour of expert system under different types of responses provided by the user

Session one illustrates the case where user wants the ultimate bearing capacity of the given foundation

Session two illustrates the case where user wants the design of foundation Because of low reliability of the supplied data, the

system is not able to design the foundation and back analysis is performed by the system

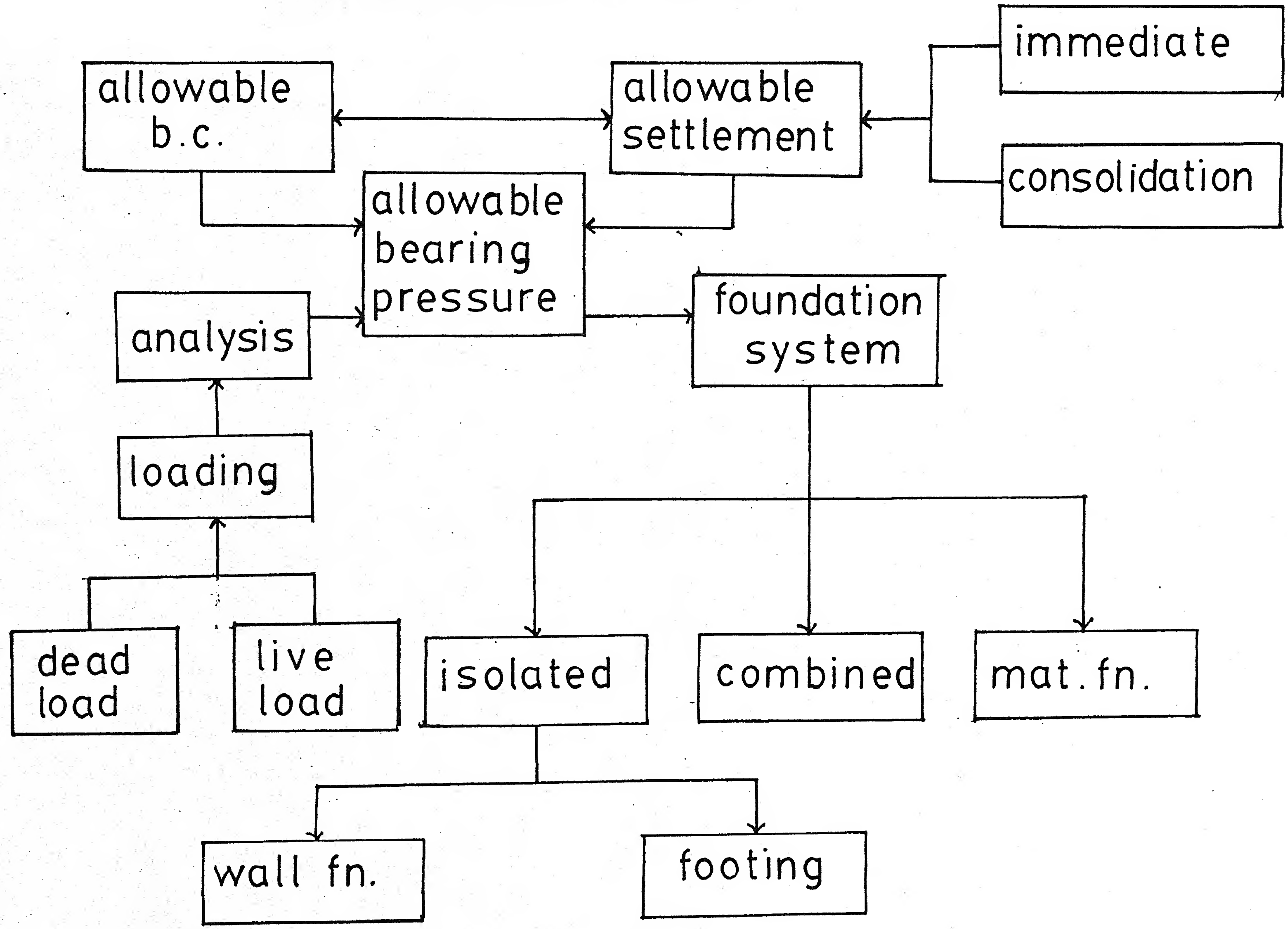


FIG 3.1 BASIC BLOCK DIAGRAM-SHALLOW FOUNDATION DESIGN

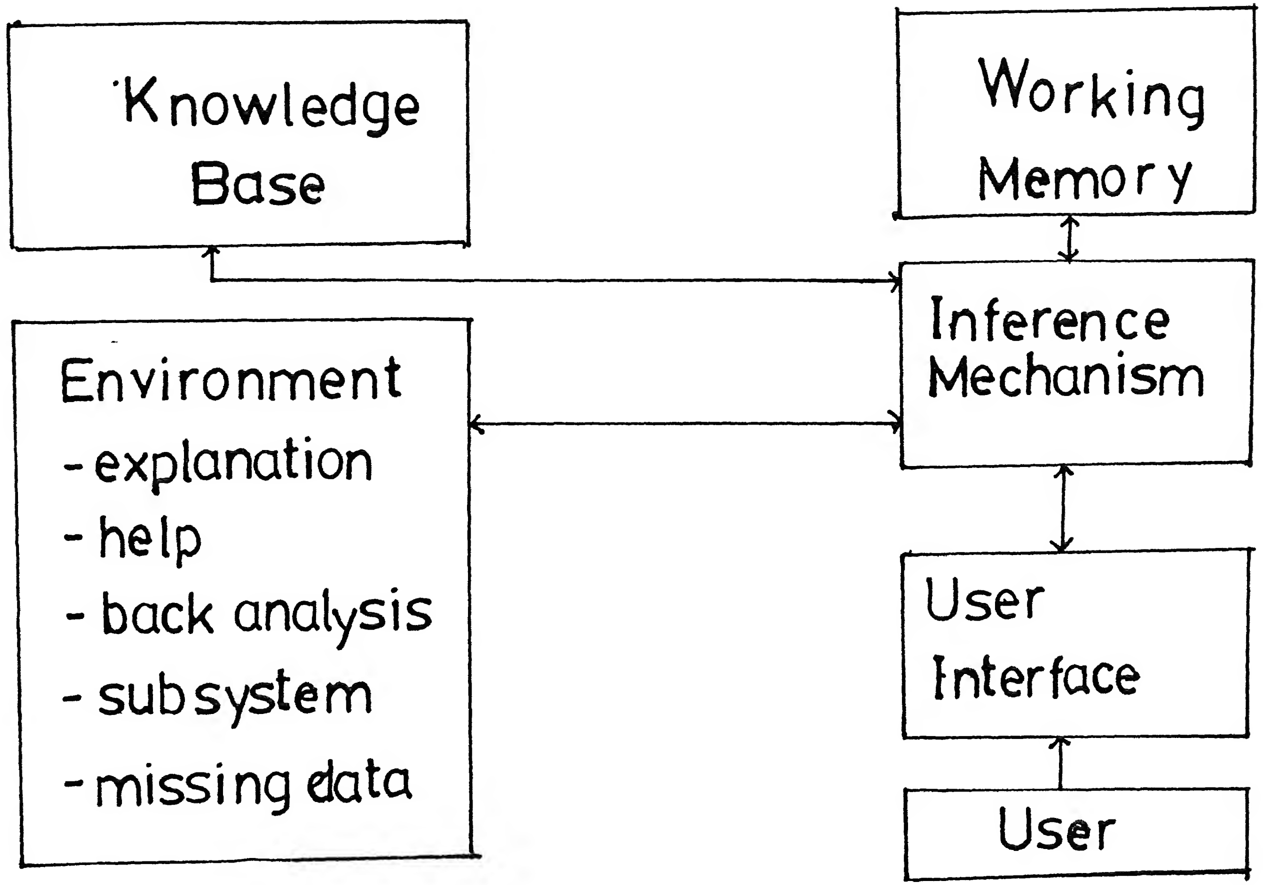

Knowledge Base
Working Memory
Environment
- explanation
- help
- back analysis
- subsystem
- missing data
Inference Mechanism
User Interface
User

Fig. 3·2

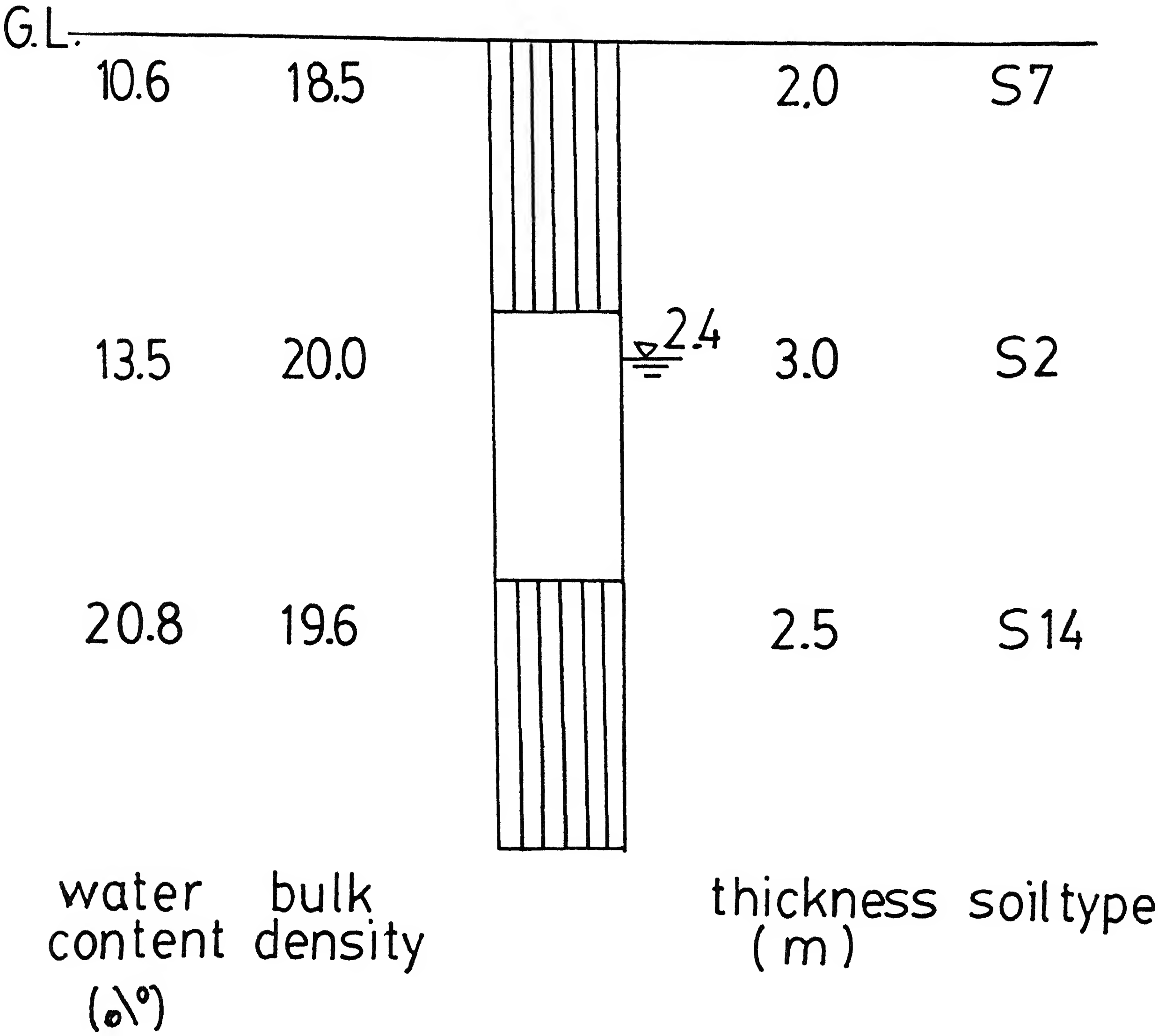


FIG 3.3 BORE-LOG PLOT

CHAPTER 4. CONCLUSIONS AND RECOMMENDATIONS

4.1 GENERAL :-

GEOTECH, an expert system has been developed to evaluate the potential of 'Application of Artificial Intelligence in Geotechnical Engineering' Several new ideas have been implemented in the system and important conclusions are obtained The limitations of the system are mostly due to time constraint and can be overcome by putting more effort

4.2 LIMITATIONS OF THE PRESENT WORK AND SCOPE FOR FUTURE WORK :-

The limitations of the present work are because of two reasons One set of limitations exist because the AI tools themselves are still facing fundamental problems like knowledge representation and context For example, experts in analysis of geotechnical failure evaluate a new case (a new failure) within a wide context of facts, identifying features resembling or clearly contrasting previous cases they studied Also, it is not possible in most cases to incorporate the large amount of contextual information relevant to particular situation

The second set of limitations are due to insufficient knowledge base. Developing knowledge-based system is task of distilling and debugging knowledge through time-consuming trial and error procedure It is indeed difficult to produce error-free system

The limitations in the present knowledge base can be

summarized as follows

a The system is only for the design of shallow foundations

b The rules for calculation of structural design (concrete grade and reinforcement required) of foundation are not included So the structural design of a foundation is not a part of this system

c In most cases, only technical aspects are considered in designing the foundation Other aspects like feasibility of foundation for particular location, environmental problem etc are not considered

d In calculating bearing capacity, the effect of presence of adjacent foundation, footing on or adjacent to slopes etc are not included.

e In settlement calculations the effect of over or under consolidation, correction for three dimensional consolidation etc. are not considered

All above technical limitations provide the scope of future work

Design of foundation requires several numerical calculations At present these are performed in LISP itself The GCLISP dose not provide even simple mathematical functions like SIN, COS, ATAN etc All these required functions are defined in the system These may not be very efficient Also, as a whole LISP is relatively very poor in numerical calculations These limitation can be overcome by providing interface of FORTRAN or PASCAL for numerical calculations

4.3 CONCLUSIONS :-

Geotechnical engineering has been and is a field where experiential information has no substitute, making it particularly suitable for the application of knowledge-based expert systems The expert system developed here for 'shallow foundation designs' makes use of COMMON LISP and runs on IBM PC-XT/AT compatible microcomputers It is capable of calculating bearing capacity, settlement and ultimately design of foundation It considers various ground characteristics like soil type, soil properties, water table etc. and structural details like load, column type, column size etc The system is tested for few cases and performance of the system is found to be entirely satisfactory

GEOTECH offers a number of useful features. modeling uncertainty, conflict resolution, back analysis, rich geotechnical environment, dealing with missing data, on-line help etc

Additional rules can be easily added in the system to include other knowledge like ground improvement, information on cost etc

The system is developed in relatively very short time period Extensive field testing is needed before the system can be put into commercial use Other features like structural design of foundations are required in the system to make it more useful Thus, the present work marks a beginning towards this ultimate goal

REFERENCES :-

1 Adeli H (eds) (1988), Expert Systems in Construction and Structural Engineering, Chapman and Hall, Reading, London, 1988.

2 Agrawal S (1989), Expert System for Thermal Design of Shell and Tube Vertical Condensers, M Tech Thesis, Dept of Mech Engg , IIT, Kanpur

3.Barr A and Feigenbaum E A (eds.) (1982), The Handbook of Artificial Intelligence, Vol 2, Morgan Kanfmann,CA, 1982

4 Bowles J E (1982), Foundation Analysis and Design, McGraw-Hill, Reading, 1982

5. Buchanan B G and Shortliffe E.H (eds)(1984), Rule-Based Expert Systems - The MYCIN Experiments of the Stanford Heuristic Programming Project, Addition Wesley, Reading, MA, 1984

6 Dong W , Shah H C and Wong F (1988), Condensation of Knowledge Base in Expert Systems with Applications to Seismic Risk Evaluation, in Expert Systems in Construction and Structural Engineering (edt Adeli H), Chapman and Hall, Reading, London, 1988, P.P 193-223

7 Harmon P , Maus R and Morrissey W (1988), Expert Systems Tools and Applications, John Wiley & Sons, Inc , Reading, NY,1988

8 Hayes-Roth F , Waterman D.A and Lenat D.B (1983), Building Expert Systems, Addition Wesley, Reading, London,1983

9 IS.1498-1970, Classification and Identification of Soil, ISI, New Delhi, 1981

10 IS 1904-1986, Code of Practice for Design and Construction of Foundations in Soils .General Requirements, ISI, New Delhi, 1986

11 IS·6403-1981, Code of Practice for Determination of Bearing Capacity of Shallow Foundations, ISI, New Delhi, 1981

12 IS 8009-1976 Part-1, Code of Practice for Calculation of Settlement of Foundations Subjected to Symmetrical Vertical loads, ISI, New Delhi, 1976

13 Jackson P (1986), Introduction to Expert Systems, Addition-Wesley, Reading, Wokingham, England, 1986.

14 Kaniraj S R (1988), Design Aid in Soil Mechanics and Foundation Engineering, Tata McGraw Hill,Reading,New Delhi, 1988

15 Levine R I , Drang D E. and Edelson B. (1987), A Comprehensive Guide to AI and Expert Systems, McGraw Hill, Reading, NY, 1987

16 McCarthy D F. (1988), Essentials of Soil MEchanics and Foundations, Prentice Hall, Reading, NJ, 1988

17. Mullarkey P W (1986), A Geotechnical KBS Using Fuzzy Logic, 1st International Conference on Application of Artificial Intelligence in Engineering Problems, Southampton University, U K., April 1986, P P. 847-859

18 O'shew T and Eisenstadt (1984) Artificial Intelligence Tools, Techniques and Applications, Harper and Row, New York, 1984

19 Sangal R (1988), Programming Paradigms in LISP, McGraw Hill, Reading, 1988

20 Santamarina J C and Chameau J L (1987), Expert Systems for Geotechnical Engineers, Journal of Computing in Civil Engineering,ASCE, Vol 1, No 4,pp 241- 251

21 Winston P H and Horn B K (1984), LISP, Addition Wesley, Reading, MA, 1984

22 Zedah L A (1965), Fuzzy Sets, Information and Control, Academic Press, Vol 8, 1965, New York

23. Zedah L A (1983), The Role of Fuzzy Logic in the Management of Uncertainty in Expert Systems, Fuzzy Sets and Systems, 11, 1983, pp 199-227

24 Zedah L A (1984), Making Computers Think like People, IEEE Spectrum, Aug 1984, pp 26-32

APPENDIX A:-

LIST OF METHODS USED IN THE SYSTEM :-

A Following methods are used in the system for calculating Bearing Capacity

METHOD	TYPE OF SOIL	REFERENCE	IMPLEMENTATION
1 TERZAGHI	HOMOGENEOUS	KANIRAJ[pp 178]	EQUATIONS
2 MAYERHO	-DO-	KANIRAJ[pp 179]	-DO-
3 B HANSEN	-DO-	KANIRAJ[pp 179]	-DO-
4 BALLA	-DO-		-DO-
5 SKEMPTON	-DO-	PUNAMIA[pp 641]	-DO-
6 VESIC	HOMOGENEOUS & NONHOMOGENEOUS	KANIRAJ[pp 179 & pp 212]	EQUATIONS & CURVE FITTING
7 BOWLES	NONHOMOGENEOUS	BOWLES [pp 151]	EQUATIONS
8 SPT + IS 6403	HOMOGENEOUS & NONHOMOGENEOUS	IS 6403 [1981]	EQUATIONS & CURVE FITTING
9 SPT + TENG	-DO-	KANIRAJ[pp 157]	EQUATIONS
10.CPT + SCHEMERTMANN	-DO-	KANIRAJ[pp 242]	EQUATIONS & CURVE FITTING
11 CPT + MAYERHOF	-DO-	KANIRAJ[pp 243]	EQUATIONS
12.CPT + BEGGMANN	-DO-	BOWLES[pp 160]	EQUATIONS
13 CPT + IS 6403	-DO-	IS 6403[1981]	CURVE FITTING
14.PLATE LOAD TEST	HOMOGENEOUS	IS.8009[1976]	EQUATIONS
15.VANE SHEAR TEST	-DO-	BOWLES[pp.208]	EQUATIONS & CURVE FITTING

b FOLLOWING METHODS ARE USED IN THE SYSTEM FOR SETTLEMENT CALCULATIONS
[ALL THE METHODS CAN BE USED FOR HOMOGENEOUS AS WELL AS NONHOMOGENEOUS SOILS]

METHOD	REFERENCE	IMPLEMENTATION
1.EQUATIONS FROM THEORY OF ELASTICITY	BOWLES[pp 183]	EQUATIONS & CURVE FITTING
2 PLATE LOAD TEST + BOND	BOWLES[pp 189]	EQUATIONS
3 PLATE LOAD TEST + IS 8009	IS 8009-1976	EQUATIONS
4 SPT + IS 8009	IS.8009-1976	EQUATIONS & CURVE FITTING
5.SPT + BOWLES	BOWLES[pp 232]	EQUATIONS
6 SPT + TENG	KANIRAJ[pp 236]	EQUATIONS
7 CPT + SCHEMERTMANN	KANIRAJ[pp 395]	EQUATIONS
8 CPT + DE BEER AND MARTEN	KANIRAJ[pp 393]	EQUATIONS
9 COEFFICIENT OF CONSOLIDATION	BOWLES[pp 197]	EQUATIONS
10 COMPRESSION INDEX	BOWLES[pp 197]	EQUATIONS
11 SECONDARY COMPRESSION INDEX	KANIRAJ[pp 384]	EQUATIONS
12 BOSSINESQUE METHOD [FOR SOIL PRESSURE]	BOWLES[pp 173]	EQUATIONS & CURVE FITTING
13.WESTERGAURD METHOD [FOR SOIL PRESSURE]	BOWLES[pp. 178]	EQUATIONS & CURVE FITTING

APPENDIX B :-

SOME SPECIAL PROGRAMMING TECHNIQUES USED IN THE SYSTEM :-

GCLISP is an interpreter which occupies large amount of memory space. When GCLISP is loaded, it secures about 576 KB RAM memory, out of which about 200 KB is used by the interpreter itself. Only about 375 KB memory is available for the program.

Generally expert system programs are much more larger than conventional programs because of very large knowledge base and its context. The performance of an ES depends upon the knowledge incorporated in the system. If more knowledge is incorporated in the system with its wide context then system will perform better. But often size of the knowledge is restricted by the availability of the memory. In GEOTECH various techniques are used to utilize available memory effectively so that more knowledge can be incorporated in the system.

After using the functions, they are unloaded. i.e. removed from the memory time to time. This is possible because LISP is an interpreter. If during execution some function is needed which is already unbounded then system will go into the error state and program will stop. To avoid this <u>AUTOLOADING</u> facility is used. As soon as the function is needed, it will <u>AUTOLOAD</u> the file in which this function or variable is defined. This facility is useful in the other way also. Program will not load all the files but files are loaded as and when required. For example, files BCNHRB1.LSP, BCNHRB2.LSP etc. are the files for nonhomogeneous soil. If given soil condition is nonhomogeneous then and then only the files are loaded.

LISP provides an excellent facility of crating and using local variables Only these variables which are required through out the execution are global variables All other variables are local variables So that as soon as they are used, they will be automatically unbounded

In foundation design several methods provide solution in the form of tables, charts etc for which interpolation is needed As LISP allows symbolic manipulation, instead of making array for this, list is used This saves considerable amount of memory For example data is given as follows

(deg)	Ø	5	1Ø	15	2Ø	25	3Ø	35	4Ø
N_q	1 Ø	1 6	2 7	4 4	7 4	12 7	22 5	36 5	41 4

In conventional language like fortran, one has to prepare array for the interpolation Here a list is prepared like

N_q = (1 Ø 1 6 2 7 4 4 7 4 12 7 22 5 36 5 41 4)

as each of the members can be accessed separately

By using all this programming techniques, it is possible to create a program three or four times larger than a program developed without using this techniques

APPENDIX- C

HOW TO USE THE SYSTEM:-

If the decisions regarding design of shallow foundations are required, the present system can be used effectively. The system is highly interactive and user friendly. It displays the relevant questions so that the user can supply the data for a particular case. Sufficient help is provided at each step to guide and to clear the doubts of the user. Other types of facilities are also provided, which the user may need during interaction. User can evoke this help menu by pressing ALT-H.

The steps to be followed in using the system are listed below:

(a) Collect as much information as possible for the desired case.

(b) Load the program by first typing 'GEOTECH'. This will first load the interpreter GCLISP. It will give the prompt "*"

(c) Start the program by either typing 'START' or pressing ALT-S.

(d) Respond to all the questions. Response can be numerical data, Y(yes), N(no), NK(not know) or any other item asked for. However, in case of doubt or before saying "Not known" press F1 to get help from the system. During interaction, for getting other type of help, press the required key at any time.

(e) When the final results are obtained, the system will display the results.

(f) Type EXIT for going to the DOS prompt or follow the steps (c) to (e) for loading other cases.

APENDIX - D

SAMPLE RUN 1

(START)

JSER WANTS TO FIND THE ULTIMATE BEARING CAPACITY FOR GIVEN FOOTING]

JP TO WHAT DEPTH SOIL DATA IS AVAILABLE? (IN METER)) 7

IS BED-ROCK AT FINITE DEPTH? (Y/N)) N

IS IT A HOMOGENEOUS SOIL ? (Y/N) Y

Warning .-

YOU CAN NOT CHANGE THIS DATA AFTERWARD
DO YOU WANT TO CHANGE LAYER NUMBERS (Y/N)? N
AT PRESENT TOTAL NUMBER OF LAYERS = 1]

IAT IS THE DEPTH OF GROUND WATER TABLE FROM G L ?(in meter) 3 5

GIVE THE FOLLOWING DETAILS FOR SOIL CLASSIFICATION
CLASSIFICATIONS USED HERE ARE ACCORDING TO IS 1498-1970

GIVE THE FOLLOWING DETAILS FOR LAYER NO 1
1 = COURSE GRAINED (50 % or less pass 75 micron IS sieve NO 8)
2 = FINE GRAINED (more than 50 % pass 75 micron IS sieve NO 8)
3 = HIGHLY ORGANIC SOIL (peat , vegetables etc)
4 = FILL ie LOOSE DUMPED MATERIAL

ENTER ONE NUMBER = 1

IVE DATA FROM SIEVE ANALYSIS)
OF COURSE FRACTION PASSING 4 75 mm IS SIEVE NUMBER 40 = 68
PASSING 75 micron IS SIEVE NUMBER 8 = 17

GIVE THE DIFFERENT LIMITS
(FOR MINUS 425 MICRON IS SIEVE -NUMBER 40- FRACTION)

liquid limit = <F1>
iquid limit is defined as water content at which,

the soil has negligible small shear strength
the consistency of soil reaches the boundary between liquid
nd plastic state
a standard groove made in the soil in a liquid apparatus
oses over a length of 25 mm for 25 blows.

[REF KANIRAJ S R 1988].

[PRESS 'M' FOR MORE HELP, ANY OTHER KEY TO GO BACK]

M

TYPICAL VALUES FOR FEW INDIAN SOILS

	LIQUID LIMIT (%)	PLASTIC LIMIT (%)
BLACK COTTON SOIL	101	28
DELHI SILT	32	22
GHAGGAR CLAY	51	25
DHANOURI CLAY	51	30
BEAS SHALE	35	19
BOMBAY MARINE CLAY	90	40
FARAKKA CLAY	105	35

[REF KANIRAJ S R 1988]

[PRESS ANY KEY]

liquid limit = 12
plastic limit = NK

certainty factor . = .7

(GIVE THE FOLLOWING DETAIL FOR LAYER 1)
BULK DENSITY (KN/m3) = 1 68

WRONG ENTRY GIVE IT AGAIN

BULK DENSITY (KN/m3) = 16 8

WATER CONTENT (in %) = 10

DEPENDS UPON YOUR RESPONSE, NOW I AM PLOTTING THE BORE-LOG YOU CAN CHECK THE VARIOUS DATA NOW. IF YOU FIND ANY MISTAKE, THAN YOU CAN STILL CHANGE THE DATA BY PRESSING <F3> OTHERWISE PRESS ANY KEY TO CONTINUE AFTER CHECKING THE DATA

[Press S for knowing the soil type]

(WHAT IS THE TYPE OF THE FOOTING ?)
(1=ISOLATED 2=COMBINED 3=MAT)
ENTER A NUMBER = 1

(WHAT IS THE SHAPE OF THE FOOTING ?)
(1=STRIP FOOTING 2=RECTANGULAR 3=CIRCULAR 4=SQUARE 5=OTHER)
ENTER A NUMBER = 4

WHAT IS THE PRINCIPAL DIMENSION OF FOOTING(b)(IN METER) = NK

```
IT IS IMPOSSIBLE TO DO THE NECESSARY CALCULATIONS
WITH OUT KNOWING THIS DATA  PLEASE OBTAIN THIS DATA
ARE YOU ABLE TO PROVIDE THIS DATA NOW (Y/N) ? Y

 WHAT IS THE PRINCIPAL DIMENSION OF FOOTING(b)(IN METER) = 1 5

(WHAT IS THE DEPTH OF THE FOOTING BELOW GROUND LEVEL?) 1 7

IS IT A SLOPING FOOTING  (Y/N)? N

IS IT A SLOPING GROUND  (Y/N)?  N

 WHETHER LOADING IS ECCENTRIC OR INCLINED (Y/N) ? N

HAVE YOU PERFORMED ANY FIELD TEST ? (Y/N) Y

 WHICH TEST ?
   1 = STANDARD PENETRATION TEST (SPT)
   2 = STATIC CONE PENETRATION TEST (CPT)
   3 = PLATE LOAD TEST (PLT)
   4 = VANE SHEAR TEST
   5 = ANY OTHER TEST
 ENTER A NUMEER = 1

PLEASE GIVE N-value  FOR LAYER NUMBER 1 = 111

  ARE YOU SURE (Y/N)? N

PLEASE GIVE N-value  FOR LAYER NUMBER 1 = 11
                   .     certainty factor        = .8

(ANY OTHER TEST ? (Y/N)) N

  HAVE YOU PERFORMED ANY LABORATORY TEST TO FIND VALUES OF
  C AND PHI(Ø) (Y/N) ? = Y

(GIVE THE VALUE FOR LAYER NUMBER 1)
        C (in kN/m 2 ) = 7 5
        phi =  27

IS THESE VALUES OBTAINED FROM TRI-AXIAL TESTS ?(Y/N) = N

                         certainty factor        =   65

GIVE THE RELATIVE DENSITY FOR LAYER NUMBER 1 (NK for Notknown) = NK
```

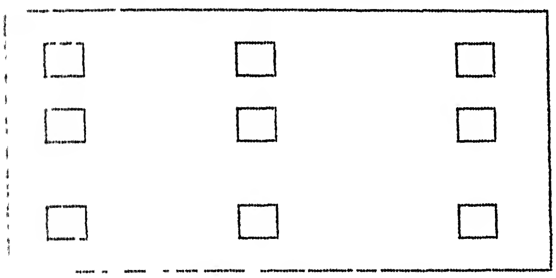
```
FOLLOWING DATA IS SUPPLIED BY YOU. IF YOU FIND ANY MISTAKE THEN STILL
YOU CAN CHANGE THE DATA BY PRESSING <F3>.

        FOUNDATION SHAPE                   = SQUARE
         PRINCIPAL DIMENSION (b)  = 1.5
         OTHER DIMENSION (l)           = 1.5
         DEPTH BELOW G.L.                = 1.7

     SPT TEST DATA
         FOR LAYER NUMBER 1        N-VALUE = 11
                 CERTAINTY FACTOR = Ø.8

     C-PHI DATA
         FOR LAYER NUMBER 1
                 C = 7.5
                 PHI = 27
                 CERTAINTY FACTOR = Ø.65
NOW I AM STARTING THE CALCULATIONS OF THE REQUIRED THINGS.
YOU CAN NOT CHANGE ANY DATA AFTER THIS REPLY.

 DO YOU WANT TO CHANGE ANY DATA (Y/N) ? N

-----------------------------------------------------------------------
         USING THE DATA OF SPT
         AND METHOD OF IS-64Ø3[1981]
         ULTIMATE BEARING CAPACITY = 44Ø.719
                  CONFIDENCE FACTOR = Ø.783
-----------------------------------------------------------------------
         ULTIMATE BEARING CAPACITY USING TERZAGHI  METHOD = 338.986
                         CONFIDENCE FACTOR = 7.38437F-Ø1
-----------------------------------------------------------------------
         ULTIMATE BEARING CAPACITY USING MAYERHOF  METHOD = 393.79
                         COMFIDENCE FACTOR = 6.99115F-Ø1
-----------------------------------------------------------------------

*
```

SAMPLE RUN 2

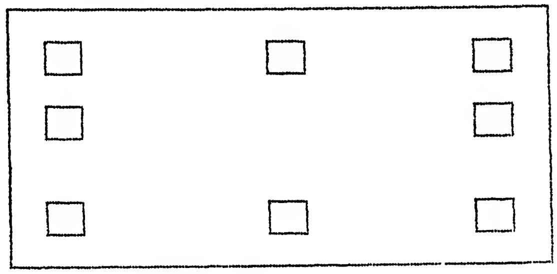
'T)

WHAT IS THE TYPE OF STRUCTURE ?
(1 = LOAD BEARING WALL STRUCTURE 2 = FRAME STRUCTURE)
ENTER A NUMBER = 2

IS IT A STRUCTURE OF REGUL@R PATTERN (Y/N) ? Y



REGULAR PATTERN

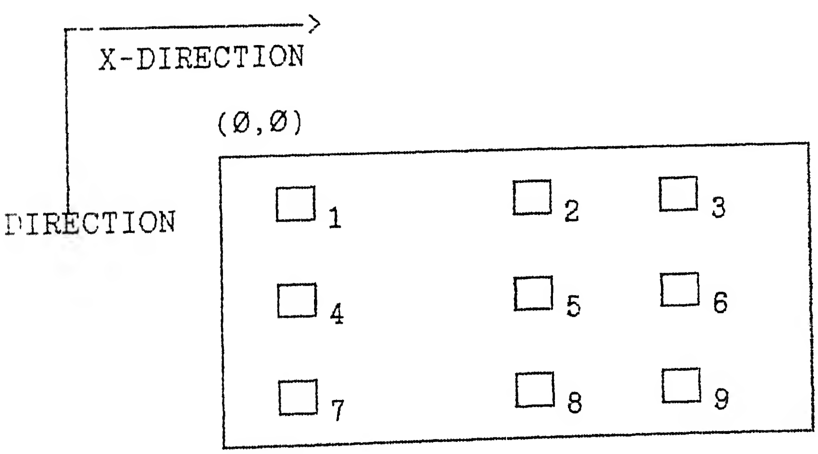


IRREGULAR PATTERN

A'L THE COLUMNS ARE ON THE INE PARALLEL LINES AND EQUAL 'OLUMNS ARE THERE ON EACH 'ARALLEL LINES

NOT ALL THE COLUMNS ARE ON PARALLEL LINES OR NUMBER OF COLUMNS ON EACH PARALLEL LINES ARE DEFERENT

NSIDER THE CO-ORDINATES OF TOP LEFT CORNER AS (Ø,Ø) AND AND Y DIRECTIONS AS SHOWN IN THE FIGURE GIVE THE DETAILS 'R EACH COLUMN. NUMBER THE COLUMN AS SHOWN IN THE FIGURE



HOW MANY COLUMNS ARE THERE IN X-DIRECTION? 2

HOW MANY COLUMNS ARE THERE IN Y-DIRECTION? 1

```
FOR COLUMN NUMBER  1

  X-COORDINATE (IN M)=  3 5

FOR COLUMN NUMBER  2

  X-COORDINATE (IN M)=  7 Ø

FOR COLUMN NUMBER  1

  Y-COORDINATE (IN M)=  2 Ø

IS ALL THE COLUMNS ARE OF SAME SHAPE ? (Y/N) Y

WHAT IS THE SHAPE OF COLUMN ?
(1 = SQUARE 2 = RECTANGULAR 3 = CIRCULAR 4 = OTHER)
ENTER A NUMBER = 2


GIVE FOLLOWING DATA FOR THE COLUMNS NUMBER 1

 WHAT IS THE MAXIMUM DESIGN LOAD (IN KN) ? 7ØØ
(PRESS S IF ALL DATA ARE SAME AS OTHER COLUMN)

WHAT ARE THE DIMENSIONS OF COLUMN ?
                IN X-DIRECTION (IN M) =  3
                IN Y-DIRECTION (IN M)  =  7

IS IT INCLINED OR ECCENTRIC (Y/N) ? N


GIVE FOLLOWING DATA FOR THE COLUMNS NUMBER 2
 WHAT IS THE MAXIMUM DESIGN LOAD (IN KN) ? 85Ø
(PRESS S IF ALL DATA ARE SAME AS OTHER COLUMN)

WHAT ARE THE DIMENSIONS OF COLUMN ?
                IN X-DIRECTION (IN M) =  3
                IN Y-DIRECTION (IN M)  =  7

IS IT INCLINED OR ECCENTRIC (Y/N) ? N




(UP TO WHAT DEPTH SOIL DATA IS AVAILABLE? (IN METER)) 1Ø

(IS BED-ROCK AT FINITE DEPTH? (Y/N)) N

      IS IT A HOMOGENEOUS SOIL ? (Y/N )  N

(HOW MANY LAYERS ARE THERE UPTO DEPTH OF 1Ø METER?) 3
```

```
Warning :-
----------
YOU CAN NOT CHANGE THIS DATA AFTERWARD.
DO YOU WANT TO CHANGE LAYER NUMBERS (Y/N)? N
[AT PRESENT TOTAL NUMBER OF LAYERS = 3 ]

(THE THICKNESS OF LAYER NUMBER 1 IN METER) 3.5

(THE THICKNESS OF LAYER NUMBER 2 IN METER) 2.5

(THE THICKNESS OF LAYER NUMBER 3 IN METER) 3

WHAT IS THE DEPTH OF GROUND WATER TABLE FROM G.L.?(in meter) 3

IS THE SOIL OVERCONSOLIDATED ? (Y/N)  N


        GIVE THE FOLLOWING  DETAILS FOR SOIL CLASSIFICATION.
        CLASSIFICATIONS USED HERE ARE ACCORDING TO IS :1498-1970

  GIVE THE FOLLOWING DETAILS FOR LAYER NO. 1
   1 = COURSE GRAINED (50 % or less pass 75 micron IS sieve NO.8)
   2 = FINE GRAINED (more than 50 % pass 75 micron IS  sieve NO.8)
   3 = HIGHLY ORGANIC SOIL (peat , vegetables etc. )
   4 = FILL ie LOOSE DUMPED MATERIAL
      ENTER ONE NUMBER  2

      GIVE THE DIFFERENT  LIMITS
      (FOR MINUS 425 MICRON IS SIEVE -NUMBER 40- FRACTION)

      liquid limit =  40
      plastic limit = 23

  GIVE THE FOLLOWING DETAILS FOR LAYER NO. 2
   1 = COURSE GRAINED (50 % or less pass 75 micron IS sieve NO.8)
   2 = FINE GRAINED (more than 50 % pass 75 micron IS  sieve NO.8)
   3 = HIGHLY ORGANIC SOIL  (peat , vegetables etc. )
      ENTER ONE NUMBER  2

      GIVE THE DIFFERENT  LIMITS
      (FOR MINUS 425 MICRON IS SIEVE -NUMBER 40- FRACTION)

      liquid limit =  34
      plastic limit = 27

      WHETHER SOIL IS HAVING ANY FEATURE OF ORGANIC SOIL LIKE
      COLOUR, ODOUR  OR  REDUCTION IN LIQUID OR PLASTIC  LIMIT
      CONSIDERABLY ON OVEN DRYING

      (Type   Y=Yes   N=No    NK = Not Known ) NK

  GIVE THE FOLLOWING DETAILS FOR LAYER NO. 3
   1 = COURSE GRAINED (50 % or less pass 75 micron IS sieve NO.8)
   2 = FINE GRAINED (more than 50 % pass 75 micron IS  sieve NO.8)
   3 = HIGHLY ORGANIC SOIL (peat , vegetables etc. )
      ENTER ONE NUMBER  2
```

GIVE THE DIFFERENT LIMITS
(FOR MINUS 425 MICRON IS SIEVE -NUMBER 4Ø- FRACTION)

liquid limit = 56
plastic limit = 4Ø

WHETHER SOIL IS HAVING ANY FEATURE OF ORGANIC SOIL LIKE COLOUR, ODOUR OR REDUCTION IN LIQUID OR PLASTIC LIMIT CONSIDERABLY ON OVEN DRYING
(Type Y=Yes N=No NK = Not Known) NK
certainty factor = .8

(GIVE THE FOLLOWING DETAIL FOR LAYER 1)
BULK DENSITY (KN/m3) = 18 2

WATER CONTENT (in %) = 17

(GIVE THE FOLLOWING DETAIL FOR LAYER 2)
BULK DENSITY (KN/m3) = 19 4

WATER CONTENT (in %) = 19

(GIVE THE FOLLOWING DETAIL FOR LAYER 3)
BULK DENSITY (KN/m3) = 19.6

WATER CONTENT (in %) = 15

DEPENDS UPON YOUR RESPONSE, NOW I AM PLOTTING THE BORE-LOG
YOU CAN CHECK THE VARIOUS DATA NOW IF YOU FIND ANY MISTAKE,
THAN YOU CAN STILL CHANGE THE DATA BY PRESSING <F3>
OTHERWISE PRESS ANY KEY TO CONTINUE AFTER CHECKING THE DATA

[Press S for knowing the soil type]

HAVE YOU PERFORMED ANY FIELD TEST ? (Y/N) N

HAVE YOU PERFORMED ANY LABORATORY TEST TO FIND VALUES OF
C AND PHI(Ø) (Y/N) ? = Y

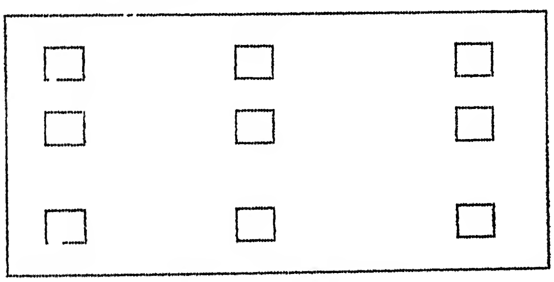
(GIVE THE VALUE FOR LAYER NUMBER 1)
C (in kN/m 2) = 25
phi = 9

(GIVE THE VALUE FOR LAYER NUMBER 2)
C (in kN/m 2) = 2Ø
phi = 18

(GIVE THE VALUE FOR LAYER NUMBER 3)
C (in kN/m 2) = 17 6
phi = 21

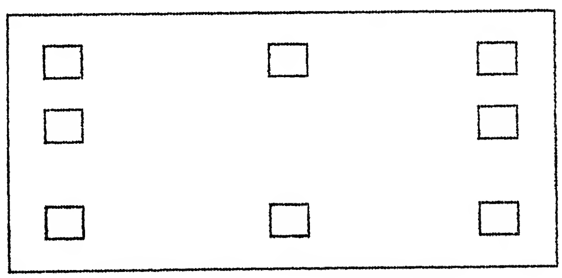
```
IS THESE VALUES OBTAINED FROM TRI-AXIAL TESTS ?(Y/N) = N
                  .......certainty factor.......=  .4

GIVE THE UNDRAINED SHEAR STRENGTH FOR THE LAYER NUMBER  1
(NK  for Notknown) = NK

(VOID RATIO - FOR LAYER NUMBER 1) = .67

  PLEASE ENTER ONE NUMBER = 4
(1 = Both Coefficient of Compressibility (mv) & Compression
     Index calculated
 2 = Only Coefficient of Compressibility (mv) calculated
 3 = Only compression Index (Cc) is calculated
 4 = Notknown )


FOLLOWING DATA IS SUPPLIED BY YOU. IF YOU FIND ANY MISTAKE THEN STILL
YOU CAN CHANGE THE DATA BY PRESSING <F3>.

    C-PHI DATA
        FOR LAYER NUMBER 1
                C = 25
                PHI = 9

        FOR LAYER NUMBER 1
                C = 2Ø
                PHI = 18

        FOR LAYER NUMBER 1
                C = 17.6
                PHI = 21
                CERTAINTY FACTOR = Ø.4




        VOID RATIO FOR LAYER 1 = Ø.67

        NUMBER OF COLUMNS =2

NOW I AM STARTING THE CALCULATIONS OF THE REQUIRED THINGS.
YOU CAN NOT CHANGE ANY DATA AFTER THIS REPLY.

 DO YOU WANT TO CHANGE ANY DATA (Y/N) ? N


  BACK ANALYSIS . . . . .

        WHILE CALCULATING BEARING CAPACITY IT IS FOUND THAT THE
        RELIABILITY  OF  DATA SUPPLIED  BY  YOU IS VERY LOW AND
        HENCE I AM NOT ABLE  TO PROCEED FURTHER. PLEASE CONDUCT
        ALL SITE INVESTIGATION PROGRAM UNDER STRICT SUPERVISION.

                . . . . . . . GOOD   BYE .   .     .      .
```

```
,FILR FOR ASKING QUESTIONS OF STRUCTURAL DETAILS .-
(DEFUN ARE-YOU-SURE ()  ,TRANFER IN INIT FILES
 (LET ((RESP))
        (PROG () LP
        (FORMAT T "ARE YOU SURE? ")
        (SETF RESP (READ-CHAR))
        (COND   ((OR (= RESP 89) (= RESP 121))(SETF RESP 1))
                ((OR (= RESP 78) (= RESP 11Ø))(SETF RESP Ø))
                (T (WE) (GO LP))))(TERPRI)
        RESP))
(DEFUN NOT-POSIBLE ()
        (FORMAT T "THIS VALUE IS NOT POSSIBLE ACCORDING TO OTHER
DATA GIVEN YOU CAN CHANGE THE WRONG DATA BY PRESSING F2")
        (TERPRI))
(CLS)
(DEFUN STR-QUES1 ()
  (PROG () LOOP
        (FORMAT T "
        WHAT IS THE TYPE OF STRUCTURE ?
        (1 = LOAD BEARING WALL STRUCTURE  2 = FRAME STRUCTURE )
        ENTER A NUMBER = ")
        (SETF STR-TYPE (READ))
        (COND ((NUMBERP STR-TYPE)
                (COND ((> STR-TYPE 2)(WE) (GO LOOP))))
                (T (WE)(GO LOOP)))) )
(STR-QUES1)

(DEFUN COL-QUES1 ()
  (PROG () LOOP
        (CLS)
        (FORMAT T "
        IS IT A STRUCTURE OF REGULAR PATTERN (Y/N) ? ")
        (RECORD-POSITION)
        (FORMAT T "
```



REGULAR PATTERN

ALL THE COLUMNS ARE ON THE LINE PARELLEL LINES AND EQUAL COLUMNS ARE THERE ON EACH PARALLEL LINES

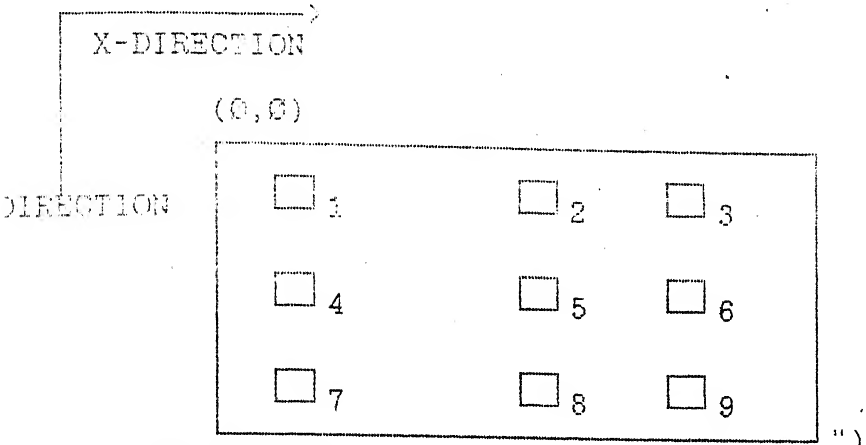


IRREGULER PATTERN

NOT ALL THE COLUMNS ARE ON PARELLEL LINES OR NUMBER OF COLUMNS ON EACH PARALLEL LINES ARE DIFFERNT.

```
(DEFUN CORNER-CORDINAT ()
(DEFPARAMETER FIGURE-WINDOW
        (MAKE-WINDOW-STREAM :TOP 1 :LEFT 14 :WIDTH 65 :HEIGHT 19))
(DEFPARAMETER *TERMINAL-IO*
        (MAKE-WINDOW-STREAM :TOP 20 :LEFT 14 :WIDTH 65 :HEIGHT 4))

 (PROG ()
        (SETF COR-COR-X (MAKE-ARRAY 3)
              COR-COR-Y (MAKE-ARRAY 3))
        (CLS)
        (FORMAT FIGURE-WINDOW "
        NUMBER THE CORNERS AS SHOWN BELOW AND GIVE THE
        CO-ORDINATES FOR THESE CORNERS.

        ---------------->
        | X-DIRECTION
        |
        |       (Ø,Ø)
        |
   Y-DIRECTION  CORNER 1                  CORNER 2



                CORNER 3                  CORNER 4
                                                    ")
LP1
        (FORMAT *TERMINAL-IO* " X-COORDINATE
        FOR CORNER NUMBER 2 = ")
        (SETF (AREF COR-COR-X 2) (READ))
        (COND ((NUMBERP (AREF COR-COR-X 2)))
                (T (WE) (GO LP1)))
LP2
        (FORMAT *TERMINAL-IO* " Y-COORDINATE
        FOR CORNER NUMBER 3 = ")
        (SETF (AREF COR-COR-Y 2) (READ))
        (COND ((NUMBERP (AREF COR-COR-Y 2)))
                (T (WE) (GO LP2)))
        ) )
 (DEFUN REGULAR-CORDINAT ()
        (CORNER-CORDINAT)
        (SEND FIGURE-WINDOW :CLEAR-SCREEN)(CLS)
```

```
(FORMAT FIGURE-WINDOW "
NSIDER THE CO-ORDINATES OF TOP LEFT CORNER AS (Ø,Ø) AND
AND Y DIRECTIONS AS SHOWN IN THE FIGURE.GIVE THE DETAILS
R EACH COLUMN. NUMBER THE COLUMN AS SHOWN IN THE FIGURE.
```




```
")
(COLUMN-NUMBER)
(SETF   COL-COR-X (MAKE-ARRAY (+ COL-NUM-X 1))
        COL-COR-Y (MAKE-ARRAY (+ COL-NUM-Y 1)))
(DO ((J 1 (+ J 1)))
        ((> J COL-NUM-X))
(PROG () LOOP
(FORMAT *TERMINAL-IO* " FOR COLUMN NUMBER ")(PRINC J)
(FORMAT *TERMINAL-IO* " X-COORDINATE (IN M)= ")
(SETF (AREF COL-COR-X J) (READ))
(COND ((NUMBERP (AREF COL-COR-X J))
        (COND((> (AREF COL-COR-X J) (AREF COR-COR-X 2))
                (NOT-POSIBLE) (GO LOOP)))
        (COND ((> J 1)
         (COND((< (AREF COL-COR-X J) (AREF COL-COR-X (- J 1)))
                (NOT-POSIBLE) (GO LOOP)))
         (COND ((> (- (AREF COL-COR-X J) (AREF COL-COR-X (- J 1))) 7)
                (IF (= (ARE-YOU-SURE) Ø)
                       (GO LOOP)))))))
      (T (WE) (GO LOOP)))))
(DO ((J  1 (+ J COL-NUM-X))
     (J1 1 (+ J1 1)))
        ((> (/ J COL-NUM-X) COL-NUM-Y))
(PROG () LOOP
(FORMAT *TERMINAL-IO* " FOR COLUMN NUMBER ")(PRINC J)
(FORMAT *TERMINAL-IO* " Y-COORDINATE (IN M)= ")
(SETF (AREF COL-COR-Y J1) (READ))
(COND ((NUMBERP (AREF COL-COR-Y J1))
        (COND((> (AREF COL-COR-Y J1) (AREF COR-COR-Y 2))
                (NOT-POSIBLE) (GO LOOP)))
        (COND ((> J 1)
         (COND ((< (AREF COL-COR-Y J1) (AREF COL-COR-Y (- J1 1)))
                (NOT-POSIBLE)(GO LOOP)))
        (COND ((> (- (AREF COL-COR-Y J1)(AREF COL-COR-Y (- J1 1))) 7)
                (IF (= (ARE-YOU-SURE) Ø)
                       (GO LOOP)))))))
```

```
;                (T (WE) (GO LOOP)))))
;; FILE FOR THE RULE BASE3

(DEFUN FIND-CONFLIC-RES-LIST-NBC1 ()
 (SETF CONFLIC-RES-LIST-NBC1
                (APPEND
        (COND ((> C41 Ø)
        (COND ((= C55 Ø)
        (COND ((> C42 Ø)
        (LIST
                        (CONS (* (/(+ C41 C42 C53) 3) Ø.8) '(251))
                        (CONS (* (/(+ C41 C42 C53) 3) Ø.75) '(252))




                        (CONS (* (/(+ C41 C42 C54) 3) Ø.6) '(253))
                        (CONS (* (/(+ C41 C42 C54) 3) Ø.55) '(254))))
                (T      '((Ø Ø)))))
                        (T      '((Ø Ø)))))
                                (T      '((Ø Ø))))
        (COND ((> C41 Ø)
        (COND ((= C55 Ø)
        (COND ((= C42 Ø)
                (LIST   (CONS (* (/(+ C41 C43) 2) Ø.7) '(256))
                        '(Ø Ø)))
                (T      '((Ø Ø)))))
                        (T      '((Ø Ø)))))
                        (T      '((Ø Ø)))) ) )  )


(DEFUN FIND-CONFLIC-RES-LIST-NBC2 ()
 (SETF CONFLIC-RES-LIST-NBC2
                (APPEND
        (COND ((> C41 Ø)
        (COND ((> C27 Ø)
        (COND ((> C4 Ø.4)
        (COND ((> C47 Ø.2)
                (LIST   (CONS (* (/(+ C41 (* Ø.7 C47) C4 C27) 3.7) Ø.9)'
                        (257))
                        (CONS (* (/(+ C41 (* Ø.7 C47) C4 C27) 3.7) Ø.85)
                         '(258))
                        (CONS (* (/(+ C41 (* Ø.7 C47) C4 C27) 3.7) Ø.8)
                        '(259))))
                (T      '((Ø Ø)))))     (T      '((Ø Ø)))))
                        (T      '((Ø Ø)))))     (T      '((Ø Ø))))
        (COND ((> C41 Ø)
        (COND ((> C27 Ø)
        (COND ((> C4 Ø.4)
        (COND ((> C49 Ø.2)
                (LIST   (CONS (* (/(+ C41 (* Ø.7 C49) C4 C27) 3.7) Ø.7)
                         '(261))
                        (CONS (* (/(+ C41 (* Ø.7 C49) C4 C27) 3.7) Ø.65)
                        '(262))
                        (CONS (* (/(+ C41 (* Ø.7 C49) C4 C27) 3.7) Ø.6)
                         '(263))))
                (T      '((Ø Ø)))))     (T      '((Ø Ø)))))
                        (T      '((Ø Ø)))))     (T      '((Ø Ø))))
```

```
COND ((> C41 Ø)
COND ((> C27 Ø)
COND ((> C3 Ø 4)
COND ((> C5Ø Ø 2)
      (LIST   (CONS (* (/(+ C41 (* Ø 7 C5Ø) C3 C27 (* Ø 7 C34)
               (+ Ø 9 C36)) 5 3) Ø.9) '(264))
              (CONS (* (/(+ C41 (* Ø 7 C5Ø) C3 C27 (* Ø 7 C34))
               4 4) Ø 85) '(266))
              (CONS (* (/(+ C41 (* Ø 7 C5Ø) C3 C27 (* Ø 7 C34))
               4 4) Ø.8) '(267))
              (CONS (* (/(+ C41 (* Ø.7 C5Ø) C3 C27 (* Ø 7 C34)
               (* Ø.8 C37)) 5.2) Ø.85) '(268))
              (CONS (* (/(+ C41 (* Ø 7 C5Ø) C3 C27 (* Ø.7 C34)
               (* Ø 8 C37)) 5.2) Ø 8) '(269))
              (CONS (* (/(+ C41 (* Ø 7 C5Ø) C3 C27 (* Ø 7 C35))
               4 4) Ø.75) '(271))
              (CONS (* (/(+ C41 (* Ø 7 C5Ø) C3 C27 (* Ø 7 C35))
               4 4) Ø.7) '(272))))
      (T      '((Ø Ø)))))    (T      '((Ø Ø)))))
              (T      '((Ø Ø)))))    (T      '((Ø Ø))))
(COND ((> C41 Ø)
(COND ((  C27 Ø)
(COND ((> C3 Ø 4)
(COND ((OR(> C51 Ø 2)(> C52 Ø.2))



      (LIST   (CONS (* (/(+ C41 (* Ø 7 C51) C3 C27) 3 7)Ø 75)'(273))
              (CONS (* (/(+ C41 (* Ø 7 C51) C3 C27) 3 7)Ø 3) '(274))
              (CONS (* (/(+ C41 (* Ø 7 C52) C3 C27) 3 7)Ø 55)'(276))
              (CONS (* (/(+ C41 (* Ø 7 C52) C3 C27) 3 7)Ø.6) '(277))
              (CONS (* (/(+ C41 (* Ø 7 C52) C3 C27) 3 7) Ø 7)
               '(278))))
      (T      '((Ø Ø)))))    (T '((Ø Ø)))))
              (T      '((Ø Ø)))))    (T      '((Ø Ø))))
(COND ((> C41 Ø)
(COND ((> C26 Ø)
(COND ((> C4 Ø 4)
(COND ((> C47 Ø 2)
      (LIST   (CONS (* (/(+ C41 (* Ø 7 C47) C4 (* Ø 9 C26))3 6) Ø 8)
               '(281))
              (CONS (* (/(+ C41 (* Ø 7 C47) C4 (* Ø 9 C26)) 3 6)
               Ø 75) '(282))
              (CONS (* (/(+ C41 (* Ø 7 C47) C4 (* Ø.9 C26)) 3 6)
               Ø.8) '(283))))
      (T      '((Ø Ø)))))    (T      '((Ø Ø)))))
              (T      '((Ø Ø)))))    (T      '((Ø Ø))))
(COND ((> C41 Ø)
(COND ((> C26 Ø)
(COND ((> C4 Ø.4)
(COND ((> C49 Ø.2)
      (LIST   (CONS (* (/(+ C41 (* Ø.7 C49) C4 (* Ø.9 C26)) 3 6)
               Ø 65) '(284))
              (CONS (* (/(+ C41 (* Ø 7 C49) C4 (* Ø 9 C26)) 3 6)
```

```
                Ø 6) '(286))
               (CONS (* (/(+ C41 (* Ø 7 C49) C4 (* Ø 9 C26)) 3 6)
                Ø 6) '(287))))
        (T      '((Ø Ø)))))    (T      '((Ø Ø)))))
               (T      '((Ø Ø)))))    (T      '((Ø Ø))))
 (COND ((> C41 Ø)
 (COND ((> C26 Ø)
 (COND ((> C3 Ø.4)
 (COND ((> C5Ø Ø 2)
        (LIST  (CONS (* (/(+ C41 (* Ø 7 C5Ø) C3 (* Ø 9 C26)
                (* Ø 7 C34)(* Ø.9 C36)) 5 2) Ø 8) '(288))
               (CONS (* (/(+ C41 (* Ø.7 C5Ø) C3 (* Ø 9 C26)
                (* Ø 7 C34)(* Ø 9 C36)) 5 2) Ø 7) '(289))
               (CONS (* (/(+ C41 (* Ø.7 C5Ø) C3 (* Ø 9 C26)
                (* Ø 7 C34)(* Ø 9 C36)) 5 2) Ø 65) '(291))
               (CONS (* (/(+ C41 (* Ø.7 C5Ø) C3 (* Ø 9 C26)
                (* Ø 7 C34)(* Ø 9 C37)) 5 2) Ø 75) '(292))
               (CONS (* (/(+ C41 (* Ø 7 C5Ø) C3 (* Ø.9 C26)
                (* Ø 7 C34)(* Ø 9 C37)) 5 2) Ø.6) '(293))))
        (T      '((Ø Ø)))))    (T      '((Ø Ø)))))
               (T      '((Ø Ø)))))    (T      '((Ø Ø))))
 (COND ((> C41 Ø)
 (COND ((> C26 Ø)
 (COND ((> C3 Ø 4)
 (COND ((OR (> C51 Ø 2) (> C52 Ø 2))
        (LIST  (CONS (* (/(+ C41 (* Ø 7 C51) C3 (* Ø.9 C26)) 3 6)
                Ø 6) '(294))
               (CONS (* (/(+ C41 (* Ø 7 C52) C3 (* Ø 9 C26)) 3.6)
                Ø 8) '(296))
               (CONS (* (/(+ C41 (* Ø 7 C52) C3 (* Ø 9 C26)) 3 6)
                Ø.55) '(297))
               (CONS (* (/(+ C41 (* Ø 7 C52) C3 (* Ø.9 C26)) 3 6)
                Ø 65) '(298))))
        (T      '((Ø Ø)))))    (T      '((Ø Ø)))))
               (T      '((Ø Ø)))))    (T      '((Ø Ø)))) ) )   )

N FIND-CONFLIC-RES-LIST-NBC ()
  (FIND-CONFLIC-RES-LIST-NBC1)(FIND-CONFLIC-RES-LIST-NBC2)
  (SETF CONFLIC-RES-LIST-NBC




   (APPEND CONFLIC-RES-LIST-NBC1 CONFLIC-RES-LIST-NBC2)) )

N CONFLICT-CHECK-NBC (X)
  (COND  ((AND (= CRN-V Ø)
               (MEMBER X '(251 253)))
          (SETF CRN-V 1) Ø)
         ((AND (= CRN-V 1)
               (MEMBER X '(251 253))) 1)
         ((AND (= CRN-SS Ø)
               (MEMBER X '(257 261 281 284)))
          (SETF CRN-SS 1) Ø)
         ((AND (= CRN-SS 1)
               (MEMBER X '(257 261 281 284))) 1)
```

```
        ((AND (= CRN-SB Ø)
              (MEMBER X '(258 262 282 286)))
         (SETF CRN-SB 1) Ø)
        ((AND (= CRN-SB 1)
              (MEMBER X '(258 262 282 286))) 1)
        ((AND (= CRN-ST Ø)
              (MEMBER X '(259 263 283 287)))
         (SETF CRN-ST 1) Ø)
        ((AND (= CRN-ST 1)
              (MEMBER X '(259 263 283 287))) 1)
        ((AND (= CRN-CS Ø)
              (MEMBER X '(264 289)))
         (SETF CRN-CS 1) Ø)
        ((AND (= CRN-CS 1)
              (MEMBER X '(264 289))) 1)
        ((AND (= CRN-CM Ø)
              (MEMBER X '(266 268 272 277 291 293 297)))
         (SETF CRN-CM 1) Ø)
        ((AND (= CRN-CM 1)
              (MEMBER X '(266 268 272 277 291 293 297))) 1)
        ((AND (= CRN-CC Ø) ,CPT-SHCEMERTMANN
              (MEMBER X '(267 269 271 274 278 288 292 298)))
         (SETF CRN-CC 1) Ø)
        ((AND (= CRN-CC 1)
              (MEMBER X '(267 269 271 274 278 288 292 298))) 1)
        ((AND (= CRN-CB Ø) ,CPT-BEGG
              (MEMBER X '(273 276 294 296)))
         (SETF CRN-CB 1) Ø)
        ((AND (= CRN-CB 1)
              (MEMBER X '(273 276 294 296))) 1)) )

FIRE-RULE-NBC (S DMU)
 ((Y (AREF BKD FN-LAYER)))
 ((OR (= S 251)(= S 253))
  (VESIC-NH-BC)) ;VESIC-NH-METHOD
 ((OR (= S 252)(= S 254)(= S 256))
  (MULTILAYER-AVERAGE-C-PHI))     ;AVE=BOWLES & USE FURTHER DIFF  METHOI
 ((OR (= S 257) (= S 261)(= S 281)(= S 284))
  (DISPLAY-METHOD-USED2 DMU 'SPT 'IS-64Ø3[1981])
  (SPT-IS-QA 1 Ø Y))
 ((OR (= S 258)(= S 262)(= S 282)(= S 286))
  (DISPLAY-METHOD-USED2 DMU 'SPT 'BOWLES[1982])
  (SBQA))
 ((OR (= S 259)(= S 263)(= S 283)(= S 287))
  (DISPLAY-METHOD-USED2 DMU 'SPT 'TENG)
  (STQA))
 ((OR (= S 264)(= S 289))
  (DISPLAY-METHOD-USED2 DMU 'CPT 'IS-64Ø3[1981])
  (CPT-IS))
 ((OR (= S 266)(= S 268)(= S 272)(= S 277)(= S 291)(= S 293)(= S 297))
  (DISPLAY-METHOD-USED2 DMU 'CPT 'MAYERHOF)
  (CPT-MAYER-QA))
```

```
        ((OR (= S 267)(= S 269)(= S 271)(= S 274)(= S 278)(= S 288)(= S
         (= S 298))
         (DISPLAY-METHOD-USED2 DMU 'CPT 'SCHEMERTMANN)
         (CPT-SCHEM-BC 2 Y))
        ((OR (= S 273)(= S 276)(= S 294)(= S 296))
         (DISPLAY-METHOD-USED2 DMU 'CPT 'BEGGMAN)
         (CPT-BEGM-SKEM-UBC 2 Y)))) )

(DEFUN DISPLAY-METHOD-USED2 (DMU NAME1 NAME2)
        (COND ((= DMU 1)
(FORMAT T (STRING-APPEND "      USING THE DATA OF " NAME1))(TERPRI)
(FORMAT T (STRING-APPEND "      AND METHOD OF " NAME2))(TERPRI)
(FORMAT T "     ULTIMATE BEARING CAPACITY = "))) )
```